THE LAWS WHICH REGULATE THE DEPOSITION OF LEAD ORE.

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PLATE V.

Drawn by W. Wallace.

NENT FORCE.

THE

LAWS WHICH REGULATE THE

DEPOSITION OF LEAD ORE IN VEINS;

ILLUSTRATED BY AN EXAMINATION OF THE GEOLOGICAL STRUCTURE OF THE MINING DISTRICTS

OF

ALSTON MOOR.

BY

WILLIAM WALLACE.

"Quid sit prius actum, respicere ætas
Nostra nequit, nisi qua ratio vestigia monstrat."—LUCR.

LONDON:
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1861.

"Nature executes all her ideas with unnumbered variations, and in works whose production occupies an immeasurable space of time. The complete idea is expressed in the totality of all things. As a philosopher brings out one idea in the most varied forms, or as a musician does so when he makes variations to a theme, so does Nature, though with still greater variety. Each individual is thus a peculiar realization of the fundamental Idea of the thing. But fertile Nature does not limit herself to exhibit performances of which the ideas are isolated; she appears to us in innumerable alternations of finite relations, which a prejudiced observer would designate as the most manifest imperfection, but which must appear to one who follows out the course of Nature to the highest point to which it should be developed in the human race, as separate acts by which the ideas of objects are revealed in their whole force to a powerful and penetrating understanding."—OERSTED'S *Soul in Nature*, p. 24.

TO

R. HUNT, Esq., F.R.S.,

KEEPER OF THE MINING RECORDS, JERMYN STREET, LONDON.

MY DEAR SIR,

WITH gratitude and pleasure I dedicate to you this humble attempt to simplify inquiries into the complicated nature of metalliferous deposits, and to lessen the hazard of mining speculations; for it is owing to your disinterested kindness, advice, and assistance that my labours are now published. I am conscious of their defects; but, if they should induce more able investigators to enter this new field of research, the object in view will at least be promoted. Whatever may be the result, let me express my sincere thanks to you, and remain with the deepest feelings of respect,

Yours,

Most truly,

W. WALLACE.

PREFACE.

To collect, arrange, and harmonize the experience of many generations on subjects relating to the knowledge of external nature is a difficult task, but more especially when the phenomena are removed from ordinary observation and seen only by few individuals, and at various periods of time.

This is peculiarly the case with everything relating to veins and the metallic deposits they contain. It is often difficult, and sometimes even impossible, to obtain information, and when obtained, it is not unfrequently mixed with error, the result of defective or bad observations. Men's ideas of a rich mine vary much, and generally fluctuate with the marketable value of the metal produced. Large profits might be obtained from mines of lead, when lead sells at twenty-five pounds per ton; but should it realize only twelve pounds per ton, the same mines might be considered as utterly worthless. Again, they vary according as the veins happen to be hard or soft, for it is manifest, that large profits might accrue from lead ore scattered in the rider of a soft vein, which would not repay the cost of extraction from that of a hard one; and unless such conditions be properly allowed for, in the investigation, it must necessarily

affect our ideas of the constancy of Nature's laws, or rather the connexion between the cause and the amount of effect produced.

For inquiries relating to this connexion the comparative richness of a vein may be indicated by two methods, either by registering the quantity of lead ore produced per *square* fathom of the vein irrespective of its width, or by the quantity produced per *solid* fathom of vein mineral worked out in order to obtain the ore exclusive of the rocky portions of pure limestone, sandstone, &c., whether comprehended in the middle of the vein or worked from its sides. In a new mining field perhaps both should be carried out in practice. I am not aware that either of these methods has ever been attempted in Alston Moor, consequently the colours upon the map which accompanies this work relate more to the comparative mercantile value of the veins than to the amount of lead ore actually deposited in them. Could the veins have been coloured so as to denote the exact quantities of lead extracted, and those in proportion to the space excavated, my impressions are that the connexion between the cause assigned in the following pages, and the effect would have been exhibited in a still more striking manner.

The map is formed by the reduction and combination of a number of general plans of mines, made by various individuals and at different periods of time. Some portions of it are very correct, while others are not so, more especially Mr. Fydell's portion of the Priorsdale Manor, and those based upon the survey of Alston Moor, completed in 1777. Respecting the mines in Killhope I have not been able to obtain either correct plans or much information. Most of the map has, however, been carefully collated with recent surveys, and the most defective

portion is sufficiently accurate to illustrate the laws relating to the distribution of lead ore in veins, and the theory of causation which comprehends the whole.

For the lines denoting the outcropping of the strata I alone am responsible; they were carefully sketched upon pocket maps during my geological rambles over the district.

While prosecuting this inquiry I have experienced the greatest kindness from the proprietors and agents of the mines in Alston Moor. The manorial plans belonging to the Greenwich Hospital were kindly placed at my service by Mr. Paull and his late father. Loans of maps have been granted me by various parties, and valuable information has invariably been given me with the greatest willingness and kindly feeling. I avail myself of this opportunity of tendering my most grateful acknowledgments to all these parties, and more especially to Mr. Walton of Greenends House, Mr. Cain, Newhouse, Weardale, and Mr. Nevin, Carshield House, West Allendale. Had it not been for the information furnished me by these three gentlemen a great portion of the map could not have been constructed.

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INTRODUCTION.

It is mainly owing to the vast stores of coal and iron, and the hardy industry and mechanical ingenuity of her sons, that Great Britain has attained such an exalted position among the nations. Her greatness is more especially dependent upon the production of coal, as a motive power, and also as an agent in the reduction of the various ores of iron and other metals: for however rich and abundant these may be, they are useless until reduced to a pure metallic state, which is now almost entirely effected by the heat derived from the combustion of coal. Without a plentiful supply of iron for tools, machinery, railroads, and implements of war, it is scarcely probable, that the ingenuity and industry of the inhabitants could support the high position she now occupies, or prevent her from sinking to a second or even to a third rate power. It has been well remarked, that it can only be after the exhaustion of the last coal-field of our country that the apocalyptic New Zealander will sketch the ruins of St. Paul's.

The tin, copper, and lead mines of the country are secondary in importance only to those of coal and iron. The investigations of geologists during the last fifty years, have, by assigning limits to the various coal-fields in different parts of the country,

taught the miner to search only in certain localities and among strata occupying a certain position, and thereby the hazard of mining for coal has been lessened. It was probably the art of mining for tin, copper, &c., that gave birth to the science of geology: so little has geology, however, yet effected towards establishing a science of mining for these metals, that it was lately stated by an eminent mining engineer, "That there were no greater facilities for ascertaining the productive character of a mine now than formerly. The difference was simply in improved machinery. Our knowledge was not greater than that of our forefathers." * This, doubtless, is substantially correct; indeed my impressions are, that mining for lead in Alston Moor is a more hazardous undertaking now than formerly. Without fundamental principles, one mining agent recommends a trial to be made, which another rejects as unworthy. Consequently, should there be funds at command, and a sufficient period of time allowed to elapse, no portions of the veins or lodes are left untried, and practically, the art of mining has degenerated into a mere trial-all system.

If such is the tendency of the present system of mining, it would appear that undue importance has been attached to the opinions of experienced men.

The business of the mining engineer includes two very distinct *agenda;* namely, the selection of suitable trials, and the construction of mining works to effect the proposed object.

In the North of England, the mining agents are chiefly selected from among the workmen, on the supposition that their experience will enable them, not only to propose suitable trials, but also to plan and direct the mining operations in the most effective and economical manner. Now, the experience of the

* Evidence before a Committee of the House of Commons on the Mines' Rating Bill, by John Taylor, Esq., June 28th, 1856.

common miner relates chiefly to the latter; and is concerned with the sinking of shafts, making of rises, levels, &c. By long-continued and daily exercise he attains a degree of skill, in penetrating the hardest rocks, in working and timbering safely, those of a soft and loose character, truly surprising. As might reasonably be expected from the appointment of men trained in such a school, the *art* of mining, so far as it relates to the construction of works, for proof of the veins, has been brought to a high degree of perfection.

But it is manifest, that employment in such labours affords no suitable training for those whose province it is to investigate the most difficult problems of geology and mineralogy. It is only in the school of Bacon that the mind can be properly disciplined for such inquiries. Habits of close observation must be combined with the intellectual power of conducting rigorous processes of inductive and deductive reasoning; and this power is only attained by profound study and reflection—by a long course of philosophic cultivation and logical habits of thinking. It may be safely affirmed, that few working miners possess the requisite time and means for prosecuting such studies. Hence while the *art* of mining has attained great perfection, the *science* of mining scarcely exists, and the opinions of practical men on the subject are based upon an empiricism of the very lowest order.

Should any one doubt the correctness of this statement, let him collect into a series of aphorisms all the exact knowledge we possess on the subject of metallic deposits in veins, and he will doubtless find the discordance in Nature to be most remarkable, and that scarcely a single proposition has yet been established which is not subject to numerous and unaccountable exceptions. That the deposition of metallic substances in veins, is an exception to that law and order which regulate the succession of

all natural phenomena properly understood, cannot for one moment be entertained, by any one thoroughly convinced of the universality and uniformity of Nature's laws. An intermixture of effects, or a phenomenon the resultant of many concurring causes, may, to the superficial observer, appear fortuitous, discordant, and mysterious; but this mysteriousness should not prevent it becoming the subject of earnest inquiry. Mystery haunts not the domain of philosophy—"Where science begins there mystery ends." *

The impossibility of arriving at any knowledge of practical value, respecting ore deposits in veins, is avowed by those who with singular inconsistency attach the greatest importance to individual experience. Even some, occupying high distinction as directors or proprietors of mines, affirm, without qualification, that it is impossible to see through solid rocks; or they summarily dismiss further consideration on the subject, by remarking, that the old adage current among miners expresses an important truth, namely—

> "It is *only* by cutting the ground
> That the metal is found."

The Cornish miners express their doubts by a similar phrase:—

> "Where it is, there it is."

If these are not the apology of indolence and ignorance they certainly are the utterances of despair. When such are the views of those, who have it more especially in their power to generalize the experience of the past, it is no wonder that our knowledge of the laws of formation and filling of veins with metallic substances does not exceed that of our forefathers; for as Bacon remarks: "Sed longe maximum progressibus scientiarum, et novis pensis ac provinciis in iisdem suscipiendis, obstaculum

* Powell's Essays 'On the Unity of Worlds' (second edition), p. 62.

deprehenditur in desperatione hominum et suppositione impossibilis."* It is the province of reason to lay open things which are under a veil, no matter how thick and opaque the material of that veil may be; or according to an ancient definition, it leads one from facts perceived to that which was not perceived.†

The finality in the progress of the science of mining is disastrous to the interests of practical mining. Advantage is taken in seasons of prosperity to make numerous trials, few of which are attended with successful results. Doubtless many of these would be considered worthless, after investigations based upon general laws, even of an empirical character,—but carefully eliminated from a wide range of facts. The consequence is, that a great part of the large profits which ought to result from the working of rich veins is wasted; or, if the mines are poor, the expense of these worthless speculations proves ruinous to the proprietors, often terminates in their embarrassment, and ultimately leads to the abandonment of the mines.

It may be well to remind those who are not satisfied unless every object suggested is proved by mining works, that mining is one of the dearest departments of the school of experience; and, as now conducted, Mr. Taylor is convinced, that, on a large scale, as much is paid for dead work as for raising the ore. Notwithstanding that this fact is well known to mine agents and proprietors of mines, no attempt has been made to classify and arrange the phenomena, ascertained to exist in Alston Moor and the adjacent districts, by the extensive explorations which have been made in the veins during the last hundred and twenty years. Had this been done forty or fifty years ago, the risk of mining

* 'Novum Organum,' Lib. i. Ap. 92.

† "Ratio, quæ ex rebus perceptis, ad id quod non percipiebatur, adducit."—Cic. *Acad. Quæstiones*, lib. iv., 8. 26.

operations, in these districts at least, would have been much diminished, and large sums spent abortively would have been saved.

So expensive are mining explorations, that it is absolutely necessary, for all who aspire to project and conduct such works, "to determine not to conjecture and divine, but to find out and know;" and they may rest assured that "neither genius, thought, nor argument can be substituted for this labour, search, and inspection (*mundanæ perambulationi*)." Their first step must be to obtain a knowledge as perfect as possible of the geological structure of the district, and, as there is a natural antipathy to descend below the Earth's surface, should this prevent them making the necessary observations, they certainly are unfit to discharge the duties they are expected to perform; and their interference must prove prejudicial, if not ruinous, to the interests of the proprietors of the mines.*

This labour of personal observation should be pursued unremittingly, as it is the nature of mining works to efface the

* The passage—from which the extracts in this paragraph are taken—was, when written, applicable to the state of science in general. It is, however, so peculiarly appropriate to the *science* of mining at the present time, that I cannot forbear giving it and the two short succeeding paragraphs entire. "Verum iis, quibus non conjicere et hariolari, sed invenire et scire propositum est; quique non simiolas et fabulas mundorum comminisci, sed hujus ipsius veri mundi naturam introspicere et velut dissecare in animo habent; omnia a rebus ipsis petenda sunt. Neque huic labori, et inquisitioni, ac mundanæ perambulationi, ulla ingenii, aut meditationis, aut argumentationis substitutio, aut compensatio sufficere potest; non si omnia omnium ingenia coieruit. Itaque aut hoc prorsus habendum, aut negotium in perpetuum deserendum. Ad hunc vero usque diem ita cum hominibus actum est, ut minime mirum sit, si natura sui copiam non faciat.

"Nam primo, sensus ipsius informatio, et deserens et fallens: observatio, indiligens et inæqualis, et tanquam fortuita; traditio, vana et ex rumore: practica operi intenta et servilis: vis experimentalis, cæca, stupida, vaga, et prærupta: denique historia naturalis, levis et inops: vitiosissemam materiam intellectui ad philosophiam et scientias congesserunt.

"Deinde, præpostera argumentandi subtilitas et ventilatio, serum rebus plane desperatis tentat remedium: nec negotium ullo modo restituit, aut errores separat. Itaque nulla spes majoris augmenti ac progressus sita est, nisi in restauratione quadam scientiarum."—BACON'S *Inst. Magna.*

phenomena they bring to light. The works frequently close up soon after they are made, or are abandoned; and even when adits and other openings are preserved by walls, &c. the very means of keeping them open prevent further inspection. When walls or timber do not intervene, deposits of dirt, lime, or oxide of iron conceal everything from view almost as effectually. Hence, everything should be carefully observed and recorded when the openings are made.

Impressed with the importance of research, and careful investigations in preventing an undue expenditure in mining works, about the latter part of the year 1847 I commenced copying numerous plans of the Alston Manor, and the adjacent ones, and resurveyed carefully the whole of the Nenthead district both internally and externally. My principal object was, if possible, to find out some particular condition, or rather phenomenon, which as the cause of ore deposits invariably co-existed with them; and thus throw some light on the distribution of lead ore in veins. I need hardly inform the student of Nature that these investigations proved a total failure. They convinced me, however, of the folly of pursuing such inquiries in the mazes of experience, without any theory, or guiding principle of causation.

A few years later, I had some reasons for concluding that increased responsibilities in connexion with the Nenthead mines devolved upon me. I then began to investigate the matter still more carefully, and endeavoured to look upon the phenomena connected with the rich portion, and those connected with the poor portion of the same vein, as two distinct machines, each having separate functions to perform. What these were, was the problem attempted to be solved. Whether this is done correctly or not will remain for the scientific reader to determine. The subject, however, has cost me much labour and thought;

and should I not succeed in unfolding a principle of causation, and that, one the most important to mining interests, I may be allowed at least the credit of collecting and arranging a large number of facts illustrating some other principle *that is true*. It may however be observed, that the principle of causation, which the following pages, but more particularly those of the second book, are intended to unfold, has enabled me, in most instances, to anticipate the results of trials, made in the Nenthead veins in the upper beds.

This principle of causation appears also to sustain the various characters of truth, " an agreement with facts such as will stand the most patient and rigid inquiry; a provision for predicting truly the results of untried cases; a consilience of induction from various classes of facts; and a progressive tendency of the scheme to simplicity and unity."* Mistakes may however occur, without affecting its truth, for careful inductions must often be made in order to bring some particular case under the general law. Eclipses of the sun and moon may be calculated with great exactness from necessary laws; the truth of which is altogether independent of the fallibility of those who make the calculations.

The first book of this work will relate to the geology of the district, and the laws of the formation and direction of veins. It is not designed to instruct those deeply versed in the science of physical geology; but a far more numerous class engaged with practical mining. That portion, which will be devoted to veins, may serve to dispel the common error, that veins may exist anywhere, and that no principle can be discovered to guide the miner in searching for them, or lessen the hazard of his expensive explorations.

* Dr. Whewell's 'Novum Organon Renovatum,' page 128.

The second book will relate chiefly to the filling up of veins with lead ore. As the most natural arrangement, I intend to follow the order and succession of ideas, as gradually unfolded in my own mind. I can hardly hope that the foundation of facts, on which the reasoning (as well as the construction of the accompanying map) will depend, is in all cases free from error. These must necessarily occur, in a first attempt of this kind; and can only be removed by the suggestions of those interested in the investigations. I have however taken much pains to ascertain their correctness, and not unfrequently has theory, which the facts are intended to support, led to further inquiry and the correction of the latter. To delay the publication of a work of this kind until perfected, would prevent its publication altogether. Perhaps I may be permitted to adopt the apology of an eastern writer, though somewhat modified: "What cannot be known with perfect precision, ought not to be totally neglected, for a knowledge somewhat imperfect is better than the ignorance of the whole."*

As to the execution of the work, I beg the indulgence of the highly educated reader, as it has not been my lot to obtain the inestimable boon of a careful literary training, without which, few ever attain the art of writing purely and perspicuously. Besides, had I possessed this advantage, the distraction of thought unavoidably caused by the performance of official duties, necessarily tends to render the style unequal, and the chain of ideas somewhat broken and disconnected, especially upon a difficult subject depending upon long and intricate investigations, carried on in a locality where there is no assistance to be obtained from scientific libraries, or intercourse with scientific men. The apology of Sir Thomas Browne is likely to be more

* Oackley's 'History of the Saracens.'

applicable to the pages which have to follow, than to the work to which they were originally prefixed.

"And first we crave exceeding pardon in the audacity of the attempt; humbly acknowledging a work of such concernment unto truth, and difficulty in itself, did well deserve the conjunction of many heads. And surely more advantageous had it been unto truth, to have fallen into the endeavours of some co-operating advancers, that might have performed it to the life, and added authority thereto; which the privacy of our condition, and unequal abilities cannot expect. Whereby notwithstanding we have not been diverted; nor have our solitary attempts been so discouraged, as to despair the favourable book of learning upon our single and unsupported endeavours.

"Nor have we let fall our pen upon discouragement of contradiction, unbelief, and difficulty of dissuasion from radicated beliefs, and points of high prescription; although we are very sensible how hardly teaching years do learn, what roots old age contracteth into errors, and how such as are but acorns in our younger brows grow oaks in our elder heads, and become inflexible into the powerfullest arm of reason. Although we have beheld, what cold requitals others have found in their several redemptions of truth; and how their ingenuous enquiries have been dismissed with censure, and obloquy of singularities."*

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* 'Pseudodoxia Epidemica.'

BOOK I.

THE FORMATION AND GEOLOGICAL STRUCTURE OF THE MINING DISTRICTS OF ALSTON MOOR.

CHAPTER I.

ON THE LAWS WHICH HAVE REGULATED THE DEPOSITION OF THE MOUNTAIN LIMESTONE IN GREAT BRITAIN.

WHEN we endeavour to trace the causes by which the present state of things, upon the surface and in the interior of the Earth, has been evolved, we only proceed a short distance until the twilight of uncertainties shrouds many of them from our view; and though all of them extend in linked succession through an incalculable antiquity, yet it is only some that have recorded their effects in "Nature's infinite book of secrecy." The analogy of past events to those effected on the surface and interior of the Earth, by causes now in operation, forms the key by which the stony records are deciphered. Of many events that have transpired, no records exist, or, as they extend into the past, are dimmed by the effacing touches of ceaseless mutation or perpetual change.

The greater portion of the knowledge we possess respecting the interior of the Earth is the result of the labours of many eminent geologists during the last fifty or sixty years; and the least disputed portions of that knowledge, are those relating to the chemical composition of all kinds of rocks, and the order of succession of the sedimentary ones—from the lowest point where they are metamorphosed, or their distinctive characteristics obliterated by Plutonic agency, to the latest deposits, now being effected, in the oceans and seas which surround the dry land. These rocks they have classified and separated into

certain groups, the exact relative position of each being well defined, at least as they are found to exist in the British islands.

The lowest of these groups is termed the Cambrian. This group of sedimentary beds rests upon Granite, and contains few organic remains. They were formerly known by the names of Lower Greywacke, Mica-Schist, and Quartz rocks; and are well developed in North Wales, and the lake district of Cumberland. Sir R. Murchison, relying on the measurements of the government surveyors, made at Longmynd, estimates the total thickness of these azoic rocks at not less than 26,000 feet. The veins traversing them often contain copper ores, near the junction of intrusive trap rocks.

Upon these metamorphic rocks rests the older Palæozoic group. It is composed of two divisions, respectively termed Upper and Lower Silurian. The former consists of the Ludlow and Wenlock beds; the latter of Caradoc and Llandillo flags. All these rocks are formed of alternating sandstones, limestones, and shale; the greater portion, however, is composed of the last; and they all contain fossils which are of a marine character.* Their thickness is estimated by the same authority at 30,000 feet, making a total with the underlying Cambrians, which bear a somewhat similar, though more crystalline aspect, of 56,000 feet—or a pile of subaqueous deposits reaching to the stupendous height of upwards of ten miles! †

* "The strata comprised in the Silurian system present all the usual characters of marine sedimentary deposits. The fossils comprise immense numbers of extinct crustaceans, and of brachiopodous mollusca, some marine worms, and many cephalopoda, crinoidea, and corals; a few placoid fishes, are the only vestiges of vertebrated animals; and fucoid plants the sole indications of the vegetable kingdom; not a vestige of any terrestrial animal or plant has been discovered. These organic remains belong for the most part to peculiar types, some of which extend into the upper Palæozoic formations, but none occur in the secondary deposits."—Dr. Mantell's 'Wonders of Geology,' p. 803.

† 'Siluria' (first edition), p. 175.

Remembering that this vast thickness of rocks is widely disseminated, not only in the British Isles, but also in the continents of Europe, Asia, America, and Australia, and that the greatest part of them is composed of finely comminuted particles of rocks which must have had a prior existence, and which, being elevated above the level of the sea, formed shores to be washed and disintegrated by the breakers; while at the same time, their whole elevated surface must have been subjected to gradual degradation by pluvial and fluvial forces, and the particles of disintegrated matter, transported by the latter to the ocean, upon whose subsiding bed, they were spread out and consolidated; and remembering, also, the slowness of operations identical in character with those now being effected upon the surface of the earth by the same forces; the mind grows giddy, not only with the contemplation of the "abyss of time," but also of space filled with these groups of rocks.

The next strata, in the order of upward succession, are the Devonian, forming the lowest portion of the upper Palæozoic rocks, and so well known as the Old Red Sandstone, from the description of their physical development and zoological contents in Scotland, by the lamented Hugh Miller. In the Lake district of Cumberland they exist as beds of coarse conglomerate, resting unconformably on the slates. A bed of conglomerate alternating regularly with the other strata, bassets to the surface on the western escarpment of Cross Fell. If this conglomerate is identical with those similar beds on the west side of the valley of the Eden, there is reason to suppose that the Old Red Sandstone is more developed under the base of Cross Fell, or on the east side of the Penine fault, than in the Lake district; but whether in the former district the Old Red Sandstone rests conformably or unconformably upon the slates, is not known; their junction being below the base of the mountain.

The other groups of the newer Palæozoic rocks, consisting of the Mountain Limestone, Millstone Grit, Coal-measures, and New Red Sandstone, repose conformably upon the Old Red Sandstone; and in the north of England, excepting the last, they all pass into each other by regular alternation, and are well developed in the tract of country, about sixty miles broad, lying on the west side of a line drawn from Nottingham to Berwick-upon-Tweed, a distance of about two hundred miles. The New Red Sandstone is also widely developed on the east side of the island, and as we have observed, its beds are not conformable to those of the Coal-measures. The line separating these two groups of rocks extends from Nottingham to Tynemouth, and slightly curves to the west opposite the Lake district of Cumberland.

Mr. Page, in his advanced 'Text-Book of Geology,' observes "that the Mountain or Carboniferous Limestone is one of the most distinct and unmistakable in the whole crust of the earth. Whether consisting of one thick, reef-like bed of limestone, or of many beds with alternating shales and gritty sandstones, its peculiar corals, encrinites, and shells distinguish it at once from all other series of strata. In fact, it forms in the rocky crust a zone, so marked and peculiar, that it becomes a guiding-post, not only to the miner in the Carboniferous system, but to the geologist in his researches among other strata." In the district whose boundaries we have roughly indicated, the Mountain Limestone is well developed, and constitutes the principal portion of these rocks in England. They are, however, more widely developed in Ireland, where, in connection with the Devonian group, they cover four-fifths of the island.* They are also widely developed in Russia, North America, and many other parts of the world.

* Johnstone's 'Physical Atlas.'

In the north of England its total thickness is about 2800 feet, and consists of a series of alternating strata of limestone, sandstone, and shale, and one layer of trap rock. The upper portion of this series bassets on the sides of the valleys of the higher parts of the South Tyne, Wear, and Tees, forming the rocks of the lead mining districts. In Alston Moor, the aggregate thickness of these rocks is 1037 feet, and they are composed of 183 feet of limestone, 349 of sandstone, and 505 feet of shale. The bed or layer of basaltic rock may be considered as forming the base of the Alston Moor mineral strata, and it only out-crops in two or three places. The lower portion of the Mountain Limestone bassets on the western escarpment of Cross Fell. The section Plate I., drawn to a scale of 200 feet in an inch, shows the total thickness of the Mountain Limestone, as well as the comparative thickness of each stratum. These, however, vary much in different localities: the section can therefore only be considered as a general representation. In the Alston Moor district, it is rarely that any particular stratum is altogether wanting. In the Tees-side and Troutbeck mines, the strata above the Whin vary considerably in order and thickness from those which out-crop near the Tyne river at Garrigill, as may be observed by comparing the section Plate II. with the general section Plate I., which may considered a faithful representation of the strata in the latter district. In the Tees-side district, a greater thickness intervenes between the top of the Whin and the bottom of the Scar Limestone, than in the Garrigill district; but in the latter, the Whin is very considerably thicker than in the former, and the distance in each case between the bottom of the Whin and the bottom of the Scar Limestone is very nearly equal. The Copper hazles are also better developed in the Tees-side than in the Garrigill district. At Long Cleugh mine, the Firestone stratum is 54 feet in thickness, but not more than half a mile in a north-west direction,

it only exists as a thin bed of famp, while the Ironstone in the same district increases from a few inches to a stratum of very hard sandstone 12 or 14 feet thick. The limestone strata vary the least, being of a uniform thickness throughout wide areas. The beds of shale vary to some extent more than the limestone strata, and the sandstones vary to a still greater extent, especially those of a coarse description. The limestones generally repose upon a bed of sandstone; if a bed of shale intervenes, it is rarely more than a few inches thick.

In addition to the minor variations which occur in all localities, this group of rocks, in the district under consideration, is subjected to a general modification of its constituent parts by the substitution of limestone for sandstone and shale, in a direction from north to south. According to Mr. Forster, who quotes from Mr. Farey's Derbyshire report, its lower part in this district is formed of 870 feet thick of limestone, with three beds of igneous rock interspersed, whose aggregate thickness is 240 feet, surmounted, as Mr. Phillips observes, "by shale with their alternations of sandstone, limestone, ironstone, &c., 500 feet, and the hills are crowned by bold ranges of Millstone Grit, and its accompanying sandstones 360 feet in thickness."*

The Great Limestone of Alston Moor can be traced to Lunedale in Yorkshire, and from thence to Wensleydale, and at each place the variation in thickness is not great. In the Long Cleugh mine, Nenthead district, it is nearly twelve fathoms thick; in Wensleydale it is called the "Twelve fathoms limestone." Its thickness is also uniform in an east and west direction; from the furthest point it has been traced eastward in the Derwent mines to the western side of Cross Fell. From Coal Cleugh it can be traced to Cupola Bridge in Whitfield, where it

* 'Manual of Geology,' p. 167.

sinks below the bed of the Allen. It, however, reappears at the surface on the north side of the Tyne, in the Haydon Bridge mining district, where the Tumbler beds are separated from the more compact limestone by a thick bed of plate or shale and another of sandstone. The Tumbler beds are also divided into two portions by a bed of sandstone. These changes are shown upon the section of the strata of this district, Plate III. In Alston Moor the Tumbler beds are separated from the limestone by a thin bed of shale, not more than 12 inches thick.

The Great Limestone invariably contains large numbers of organic remains, as shells, madrepore, corals, &c.; in consequence, it must have been deposited in a sea of moderate and uniform depth. Upon a section on the line of the Penine range of mountains, or in a direction north and south, and representing the strata as originally deposited, this limestone ought to be drawn in a horizontal position; at least, in that portion comprehended between Cross Fell and Wensleydale.

Assuming that the Great Melmerby Scar Limestone was deposited uniformly throughout the same wide area, and in a sea of moderate depth, we might expect to find some correspondence in thickness at the two places between the top of the Great Limestone and the bottom of the Melmerby Scar Limestone. At Cross Fell, according to section Plate I., which agrees with Mr. Forster's, the depth from the top of the former to the bottom of the latter is 1200 feet. The section of the Mountain Limestone and Millstone Grit in Wensleydale, as given by Mr. Phillips, is as follows:—

		Feet.
Millstone Grit series.	Coarse and fine sandstone, shales, and coal Coarse, fine, and slaty sandstones, shales, cherty beds, and coal Millstone Grit of Ingleborough, shales, cherts, and coal	700
Upper Limestone Belt.	Thin limestones, sandstone, shale Main, or 12 fathoms limestone Shales, sandstones, and coal underset limestone.	200

		Feet.
Flagstone series.	Alternations of flagstones, of various quality, in great abundance, with shales, coal, hard gritstones, and three or four strata of limestone from 6 to 30 feet thick. The black marble of Dent is nearly at the bottom of this group.	500
Scar Limestones.	Limestones of great thickness, with partings principally of shale.	500

The exact position of the "Twelve fathoms limestone" is not given in the above section; but it appears from the order to be comprehended in the central part of the Upper limestone belt; consequently, the distance from the bottom of the Scar Limestone to the top of this limestone does not differ materially from that intervening between the bottom of the Melmerby Scar Limestone and the Great Limestone, as developed in Alston Moor; and probably if very accurate measurements were taken at each place the agreement would be found still more close. This thickness also corresponds with that of the mineral limestones and toadstones of Derbyshire. We may therefore conclude that the deposition of the Melmerby Scar Limestone, and the Scar Limestone of Yorkshire and Derbyshire, took place at the same period, and upon a sea-bottom nearly horizontal; and also, that during the long period intervening between the commencement of the deposition of the Melmerby Scar Limestone and the termination of that of the Great Limestone, the rate of subsidence was nearly uniform throughout the wide area occupied by the Mountain Limestone in the central part of England.

If these views are admitted to be correct, then the series of beds comprehended between the top of the Great Limestone and Grindstone Sill in Alston Moor will correspond with the limestone shale of Derbyshire, the thickness in each case being 480 feet; and the Millstone Grit, which is fully developed in Alston Moor, will correspond to the grits of Derbyshire and Wensleydale, with some little variation in thickness. It is not improbable, however, that the Millstone Grit on the tops of the moun-

tains of Derbyshire and Wensleydale may have been degraded by denudation. In Alston Moor the thickness of strata intervening between the Great Limestone and Brockwell's coal is 935 feet. In Wensleydale, according to the section of Mr. Phillips, it is upwards of 700 feet, and in Derbyshire it is not less than 840 feet.

The following section, Plate IV., will show more clearly the views we have attempted to express in the preceding paragraphs; it denotes the regular and horizontal manner in which the strata were originally thrown down. The deposition of the sandstones in the north of England must have been equally slow with that of the limestone of Derbyshire. It is also necessary to observe, that the space occupied by the Toadstones, but for their overflow, would have been filled with limestone, and comprehended in a single stratum 1110 feet or upwards in thickness.

At Fallow Field, near Hexham, the space intervening between the bottom of the Whin and the top of the Great Limestone, corresponds very nearly to the space intervening between the same beds in Alston Moor. The correspondence in the upper portion is less striking, and may be due to some local and unequal rate of subsidence.

The law of deposition appears evident. The organically derived limestones must have been deposited in a wide sea, the bottom of which, throughout its whole extent, was gradually subsiding, probably at unequal rates in time. The space afforded by this subsidence was less than the bulk of matter deposited. The sea would therefore be gradually filled; and the sandy sediment, derived from the waste of its coasts, and the deltas of rivers, would be spread by currents in an orderly manner upon the limestones which had previously been deposited in its deeper parts. After the Great Limestone was

deposited the rate of subsidence became slower, and a shallow sea was filled with sandy sediment forming the upper part of the Mountain Limestone of Alston Moor, or the shales of Derbyshire, and, ultimately, the Millstone Grit and Coal-measures; the seams of coal in the latter resulting from a luxuriant vegetation due to a hot climate, or, at least, to plants growing in one of equable temperature, upon extensive marshes, which such conditions were likely to produce.

Although it does not form a part of our plan to enter into considerations respecting the geological structure of the neighbouring districts, we may, notwithstanding, be permitted to observe, that a portion of the Cumberland and Westmoreland Lake districts was probably dry land during the whole of the long period embracing the beginning and termination of the deposition of the Carboniferous system, or newer Palæozoic rocks. Those districts may have existed as a number of low islands surrounded by seas of moderate depth, which were gradually filled, first with the conglomerates of the Old Red Sandstone, and afterwards with limestone; forming, as Professor Sedgwick observes, "a fringing coral reef round the cluster of the Lake mountains."* The bottom of this sea must have subsided slower than that to the east of the Penine fault; or perhaps it ceased to subside after the formation of the coral reef, and during the whole of the time of the deposition of the Millstone Grit and Coal-measures. On the south and west sides, where the great coal field of Lancashire and that of Whitehaven are now worked, the rate of subsidence appears to have been very similar.

The Carboniferous system is more developed in South Wales than in the north of England. According to Mr. Phillips, "the Scar Limestone almost unmixed with any sedimentary matter is 1895 feet thick. From this we may infer that its deposition

* 'Letters on the Lake District.'

took place at a greater distance from the shore, and in a deeper sea. Ultimately, however, at the time of the formation of the Millstone Grit and Coal-measures, the conditions must have been very similar, as will appear from the following general section:—

	Feet.
Coal formation—no limestone (plants)	11,000
Millstone grit (called Farewell Rock, &c.), plants ..	300
Scar limestone (corals, &c.)	1,900
Lower shales, limestone (fish-beds, &c., a few plants) ..	400
Total	13,600

Or, an aggregate thickness of nearly two and three quarter miles."*

In Scotland the limestones of the lower part of the Carboniferous system are very thin, as will appear from the following section of the rocks in the country between Edinburgh and Glasgow.

	Feet.
Red sandstone (carboniferous)	
Alternations of sandstone and shales, with coal and ironstone	130·0
Limestone	1·0
Alternations, &c., five beds of coal 4 feet thick, and many others less	1635·0
'Gare' limestone	4·9
Intermediate strata	150·0
Ochrey limestone	3·0
Sandstone, with shale, &c., one coal	51·0
Limestone	4·0
Alternations, &c., four coals of 2 or 3 feet, many ironstones	405·0
1st Cawmey limestone	1·6
Shale	8·6
1st Kinshaw limestone	2·0
Alternations, and one little coal	16·4
2nd Kinshaw limestone	2·10
Shale, with ironstone bulls	29·5
2nd Cawmey limestone	4·6
Shale, with ironstone band	12·
Foulband limestone	3·6
Alternations, &c., one coal of 1 foot 8 inches	86·0
Carried forward	2580·4

* Phillips' 'Manual of Geology,' p. 169.

	Feet.
Brought forward	2580·4
3rd Cawmey limestone	2·6
Shale, with ironstone band	20·0
Main limestone	4·6
Shale and fire-clay, with one coal	29·0
Coarse limestone, with intermediate band of fire-clay ..	5·6
Sandstone, with shale and a little coal	54·0
Limestone	2·0
Fire-clay sandstone, and shale, with one small coal ..	34·0
Oyster-shell limestone (producta, &c.)	4·0
Alternations of shale, whitish sandstone and fire-clay ..	104·0
(Old red sandstone to an unknown depth.)	
* Total	2839·10

The aggregate thickness of the limestones in this section only amounts to 45 feet, or, about 1 in 62.

The same law of change from sandstones, shales, &c., to limestones, in a direction from north to south, prevails also in Ireland.

We have observed that during the whole period of the deposition of the Mountain Limestone in Great Britain, the bottom of the sea and its shores were slowly subsiding, while other lands, and probably those from whose waste the sedimentary matter was derived, must have been emerging from beneath the waters. As sandy matter must have formed the shores of this ancient sea, it would appear that the land lay to the north, with a sea of vast extent stretching to the south, very slowly but gradually increasing in depth from the shore. If the same law prevails in that wide extent of country, formed of Carboniferous and Permean rocks, triangular in form, and extending from the Gulf of Riga, in the Baltic Sea, to the Ural mountains, and bounded on the north-west by the Gulf of Finland, the lakes Ladoga, Onega, and the eastern shores of the White Sea; one might be tempted to suppose, that when the Mountain

* 'Encyclopædia Britannica,' vol. xv., p. 203 (eighth edition).

Limestone was thrown down, a continent of vast, superficial extent, stretching from these lakes &c. to the shores of Labrador, Hudson's Bay, and Barrow Straits, and comprising a vast tract of country now submerged in the Atlantic, of which the continent of Greenland is a portion, extended to the North Pole. In this case, on the continent of America, it might be expected, in a very general view, that the thickness of the limestone or deep sea strata would increase in a direction from east to the west. "The surveys of Pennsylvania and Virginia show that the south-east was the quarter whence the coarser materials of these strata were derived, so that the ancient land lay in that direction. The conglomerate which forms the general base of the Coal-measures is 1500 feet thick in the Sharp Mountain, where I saw it near Pottisville; whereas it has only a thickness of 500 feet, about thirty miles to the north-west, and dwindles gradually away when followed still further in the same direction, till its thickness is reduced to 30 feet. The limestones, on the other hand, of the Coal-measures augment as we trace them westward. Similar observations have been made in regard to the Silurian and Devonian formations in New York; the sandstones and all the mechanically formed rocks thinning out as they go westward, and the limestones thickening, as it were, at their expense. It is, therefore, clear, that the ancient land was to the east, where the Atlantic now is; the deep sea, with its banks of coral and shells to the west, or where the hydrographical basin of the Mississippi is now situated."*

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* Lyell's 'Manual' (fourth edition), p. 329.

CHAPTER II.

OF THE ELEVATION OF THE ROCKS OF ALSTON MOOR TO THE POSITION THEY NOW OCCUPY, AND THE LAWS WHICH HAVE REGULATED THE DENUDATION OF THE COUNTRY.

DURING the time of the deposition of the Carboniferous system in the central parts of England, the elevatory movements, if any took place, must have been of very limited extent. Certainly, there is no evidence to show that any intervening portion has suffered loss by denudation, which could not but have taken place had the rocks been elevated above the surface for any lengthened period of time. And from the extensive mining operations, we should certainly become acquainted with the fact, by observing the strata deposited, afterwards resting unconformably upon the denudated and abraded surface. Indeed the continuity of the soft shale and coal seams throughout wide areas is truly surprising. It is rarely that even a rill has cut a passage into them when they formed the shores of the sea. It is only in a district perfectly flat that the conditions necessary to produce such results could prevail; and such districts must have been occasionally covered with extensive marshes, whose luxuriant vegetable growths, after subsequent subsidences had taken place, were embedded and compressed into coal seams, by fresh layers of sedimentary matter deposited upon them.

The Carboniferous system was brought to a close in Great

Britain, by the elevation of the land. Apparently, this at *first* took place either by unequal rates in limited tracts of ground, or limited tracts continued to subside while other portions remained stationary. In the north of England, the period intervening between the close of the Coal-measures, and the depositions of the Magnesian Limestone, or Permian group of rocks, evidently constitutes a long geological epoch: for the matter denuded from the former, before the commencement of the deposition of the latter, is certainly very great. The abrasion of the Coal-measures and Mountain Limestone, by breaker action, must have also taken place subsequently to the commencement of the formation of the Permian rocks; the latter being not unfrequently formed of the debris of the former. An instance of this kind may be seen at Kirkby Stephen in Westmoreland, in the conglomerates of the New Red Sandstone. And Sir C. Lyell observes, that "near Bristol, in Somersetshire, and in other counties bordering the Severn, the unconformable beds of the Lower New Red, resting immediately upon the Coal, consist of a conglomerate called 'Dolomitic,' because the pebbles of older rocks are cemented together by a red or yellow base of Dolomite or magnesian limestone. This conglomerate, or breccia, for the imbedded fragments are sometimes angular, occurs in patches over the whole of the downs near Bristol, filling up the hollows and irregularities in the Mountain Limestone, and being principally composed at every spot of the debris of those rocks on which it immediately rests. At one point we find pieces of coal shale, in another of Mountain Limestone, recognisable by its peculiar shells and zoophytes."* In the north of England the Magnesian Limestone generally lies unconformably on the Carboniferous strata, being also much less broken by elevatory forces than the latter.

* 'Manual of Geology' (fourth edition), p. 305.

Taking a very general view of the district occupied by the Carboniferous system in the centre of England, it is evident, that if the length of time since these rocks began to emerge from the deep is to be measured by the effect produced by denudating forces; then, the districts now occupied by the Penine chain of mountains must have been elevated above the surface long prior to the districts situated near the eastern coasts. It is, however, questionable whether the whole of the denudation is due to breaker action; large quantities of matter may have been removed by the force of currents before the land fairly rose above the surface. But after making every allowance for the effect produced by currents, it is certain, that the great lines of faults, the existence of which is evidently due to forces of elevation or depression, were formed, and the whole of the country between the great Penine fault and the eastern coast thrown out of its original horizontal position, and more or less denuded, before the deposition of the New Red Sandstone or Magnesian Limestone.

The greater elevation of the strata on the line of the Penine range of mountains may be due either to a variation in the intensity of the elevatory forces, to lines of weakness, or of less resistance;—or to a combination of both these causes.

We have aleady pointed out that the Mountain Limestone encircling the Silurian rocks of the Cumberland and Westmoreland Lake districts is very thin, when compared with the same group of rocks on the east side of the Penine fault; and also, that the rate of subsidence of the sea bottoms in these two districts must have varied very considerably. We cannot conceive, however, of two adjoining tracts of sea bottoms subsiding slowly, but at very unequal rates, without at the same time conceiving a fracture or fault being made on the line of boundary, especially when the total difference in the amount of subsidence may ulti-

mately amount to several thousand feet. Under such circumstances, the strata first thrown down must necessarily be the most fractured and broken, on the line of such faults, as they are lowered to greater depths. It is obvious, that under such conditions faults may be forming at the same time that the strata in which they occur are in the course of being deposited; and after the formation of a vast thickness of rocks no indication of such a fault would appear at the surface.

But when the period of subsidence had terminated, and elevatory forces began to raise the rocks from the great depths to which they had sunk, it is evident, that such a line of fault would not offer the same amount of resistance as the strata lying consolidated and undisturbed. Nor is there anything improbable in the supposition, that the same causes which prevented the free subsidence of the strata, on one side of such faults, would also prove a preventive to their free elevation; or even, that the strata on one side of such faults might continue to subside while the other was being slowly elevated. Hence the greater elevation of the strata on the range of the Penine mountains may be due, in some measure at least, to a line of least resistance. Such a condition is certainly in harmony with established laws of geological changes.

The elevation of the Carboniferous series of beds, upon the sides of the mountains of the Lake district, may not have taken place contemporaneously with those on the east side of the Penine fault. Their elevation may be due to local volcanic causes of a more active character, and limited to the immediate neighbourhood of these hills; while at the same time, the greater portion of the valley of the Eden was lowered, affording space for the New Red Sandstone; which reposes unconformably upon the older class of rocks, and abuts against the terrace of Cross Fell. The general dip of the Carboniferous beds across the valley of the

Eden must, however, be the same as that on the east side of the Penine fault.

On the east side of the Penine range of mountains, there is no reason to conclude, that lines of least resistance, at all similar to that of the Penine fault, existed when the upward movement of the rocks began to take place: the portions, therefore, elevated higher than the rest, are due, as we have just observed, either to the continued subsidence of limited tracts, while other portions remained stationary or nearly so, or to a variation in the intensity of the elevatory forces. The most remarkable of these anticlinal axes or lines of greatest elevation of the strata, is one which extends eastward from the summit of Cross Fell, and curves around the source of the Tyne. From thence it extends in a north-easterly direction, and coincides very nearly with the Heaven's-water boundaries separating the basins of the Wear and Tees from that of the Tyne. At Kilhope Law, it takes a more southerly direction, and probably curves around the Allenheads mining district. The *general* strike of the beds on one side of this anticlinal axis is to the north-east, or rather very nearly due north; on the contrary side, in the valleys of the Wear and Tees, the *general* dip is to the south-east.

On the line of the Penine range of mountains, the beds rise rapidly to the summit of Cross Fell, and from thence to the point of intersection of the great Penine fault with the Standard vein. This intersection takes place in the neighbourhood of Brough. On the south-west side of the great Standard vein the beds dip very rapidly; in some parts of Lunedale the rate of inclination is as steep as the sides of the hills.

We have already observed, that the greatest amount of denudation has taken place in the elevated districts, where the Tyne, the Wear, and the Tees take their rise; it is remarkable, however, that in these districts certain lines of greatest elevation of

the strata should have suffered the least, and in consequence the range of the summits of the mountains coincides with them. To the investigation of the effect of this unequal elevation of the rocks upon the geological structure of the upper part of the basin of the South Tyne we shall now proceed. "The phenomena of rivers are highly instructive in theoretical geology, and that abrupt changes in their courses are distinct indications of variation in the nature of the formations through which they flow, as well as of *movements* undergone by these. This law holds with small rivulets as well as large streams."*

During an excursion from Lambley up the course of the Tyne river, a careful observer would note that the strata rise more rapidly than the bed of the river. At Eals, in the parish of Knaresdale, the Great Limestone forms a foundation for the bridge across the Tyne, and is gradually elevated to basset on the mountain sides. At Kirkhaugh the Scar Limestone occupies a similar position relatively to the bed of the river as the Great Limestone at Eals, and it also rises so rapidly that a portion of the town of Alston is built upon its outcropping. At Garrigill, the Great Limestone has attained an elevation on the sides of the mountains of 480 feet above the bed of the river, which here flows upon the Tyne bottom Limestone, and continues to do so almost uninterruptedly to the point where the Great Sulphur vein crosses the stream a little below Tyne head Smelt mill.

Near to Alston the river Nent branches from the Tyne in a south-east direction; and almost immediately forms a pretty cascade over the Scar Limestone, Plate V. Above the waterfall the rise of the bed of this river is much more rapid than that of the Tyne. Notwithstanding the rise of the beds, in a direction opposite to the flow of the stream, the strata gradually pass under

* Dr. Nicoll in Johnstone's 'Physical Atlas,' p. 2.

its bed. Hence the village of Nenthead, lying directly opposite to Garrigill, is built upon the Four fathoms Limestone, while the latter is built upon a bed of gravel—a former bed of the river Tyne—but occupying a position from which the Tyne bottom has been removed.

A little above Alston, Black Burn mingles its waters with the Tyne, after flowing for some considerable distance in an easterly direction, or one nearly at right angles to the course of the latter stream from Garrigill. Black Burn probably furnishes two-fifths of the water which passes through the Tyne bridge at Alston. It is formed by the union of two principal branches, Rowgill Cleugh and Shield Waters. The former of these streams flows from the highlands of Hartside and Gamblesby Fell, the latter collects its waters chiefly from the north side of Cross Fell. Black Burn and Shield Waters rise gently, and maintain nearly the same relative position with the outcropping of the Scar Limestone stratum to the neighbourhood of the Great Sulphur vein. On the south side of this vein the principal stream is called Cash Burn, the bed of which rises very rapidly to the source of the stream near Cross Fell Smelt mill.

South from the junction of Black Burn and the Tyne various streams flow into the latter from each side of the hills. On the west side the principal are Dryburn and Crossgill; on the east, Nattras Gill, Garrigill Burn, Ashgill Burn, and Clargill Burn at Tyne head.

The course of the Tyne between Haltwhistle and Tynemouth is nearly parallel with the Ninety fathoms dyke, and situated at no great distance to the north. Its direction from Haltwhistle southward is rather more than ninety degrees from its former course, as may be seen upon the best geological maps. In connexion with this great bend of the stream, it may be observed, that on the west side, the rise of the strata is more rapid to-

wards the summits of the Penine range of mountains than on the east side, and the course of the river seems to be a general boundary between the different rates of inclination.

Gilderdale and Thornup Burns flow from the west into the Tyne a few miles below Alston. The inclination of the strata is very rapid in a direction opposite to that in which these streams flow. At the top of Hartside the bottom of the Great Limestone is elevated about 1540 feet above the sea; and the difference in the amount of elevation at Hartside and Gilderdale Burn head is probably not very much. At the foot of Gilderdale Burn the bottom of the Scar Limestone is probably elevated 736 feet above the sea. The thickness of the strata intervening between the bottom of the Great Limestone and the bottom of the Scar Limestone, as represented upon the general section, is 331 feet. If we deduct this from the 1540 feet, there remain 1209 feet, denoting the elevation of the Scar Limestone at Hartside top. The difference of elevation at this point and Gilderdale Burn foot is therefore 473 feet, thus showing the inclination of the beds between these two places to be about 1 in 55. The rate of inclination between Nentforce level mouth and the point where Browngill veins cross the Tyne river is about 1 in 51.

From Alston the course of the Tyne river to its junction with Black Burn is westerly to its general direction. On the same parallel the Nent trends to the west, and the course of the Black Burn, as already observed, is nearly at right angles to the direction of the Tyne southward from the point of their junction. Now, in connexion with this tendency of the streams to run in an east and west direction, or at right angles to their general course, there exists also a variation in the direction and the rate of inclination of the strata. Between Black Burn and Gilderdale Burn, and in a direction at right angles to the former, the strata must be lying nearly horizontal, if indeed there is not an

actual rise from the former to the latter. This supposition receives support from the fact that the stratum of Whin, bassets to the surface in Gilderdale Burn, but in Black Burn it is lying a number of feet below the bed of the stream. It seems as if there had been an effort made by subterranean forces of subsidence or elevation, to form an anticlinal axis in a direction of parallelism to that which exists near the boundary of the water basins of the Tyne, the Wear, and the Tees. The greatest effect has been produced at the head of Gilderdale Burn, and the direction of this incipient axis may be shown by a line from this point, which passing for some distance down the water shed of Park Fell, is deflected to the south a little above Alston. From the latter place it bends to the north for a short distance, and then passes through Newshield Moss. On the east side of the Tyne there is, however, no indication of its existence, except in a less rapid inclination of the beds.

From Shield Waters the strata rise very rapidly to the west, and continue to rise on the south-west side of the Great Sulphur vein, until they out-crop on the contrary side of the mountain; in a direction of south 81 west (magnetic) the rate of inclination is about 1 in 8. In this district, the stratum of Whin forms the culminating ridge of the Penine range of mountains. So rapid however is the inclination of the strata, and so great is the throw of the Great Sulphur vein, that at Rodderup Fell low-level-mouth it is probably 48 feet below Black Burn.

From the point where Rodderup Fell vein crosses the Tyne, the strata rise very rapidly in the direction of Dryburn to the Great Sulphur vein; and on the south-west side of this vein they continue to rise to the anticlinal axis which intersects the Penine range of mountains at Cross Fell. Between the point where Fletcheras vein crosses the Tyne river, and Cross Fell Smelt mill, the difference of elevation of any particular stratum

(for instance the Scar Limestone), is probably not much less than 600 feet; the average rise from the former to the latter place being about 1 in 40. From the same point on the Tyne river, in an opposite direction (northward), the rate of inclination is probably not more than 1 in 300. On the west side of the Tyne river, above Fletcheras vein, and in a direction at right angles to that portion of the anticlinal axis ranging from Bel Beaver to Cross Fell, the beds have a very rapid inclination. From Browngill vein, in the direction of Littlegill Burn, they also rise very rapidly to the Great Sulphur vein.

The Nent is the principal stream that flows into the Tyne from the east side. Between Nenthead and Blaygill Burn foot its direction nearly corresponds to the dip of the beds. On the east side of the Nent an anticlinal axis is formed, corresponding in position and direction to the water-shed of the mountain separating the valleys of Nent and West Allen. In the valley of the Nent the strata are lying at various degrees of inclination to the powerful cross veins; but notwithstanding, in a section across the valley, from the summit of Middle Fell to the axis of elevation on the opposite side, they will be found at the extreme points occupying the same relative position to the datum line.

From what we have stated above, it will be perceived, that from Alston as a centre the strata rise in all directions, except to the north and north-west. The summits of the mountains which encircle the basin of the Tyne form the boundaries of this acclivity, from whence they incline in contrary directions. Through the summit of the Penine range of hills the rise is however continued, and as the strata of hard rock basset on the west side, they form a succession of terraces, stretching from the valley of the Eden to the summit of Cross Fell. We are therefore justified in concluding, that the formation of the valleys, and direction of the main streams, are connected by some

law of causation, with the inclination of the strata; or, whatever may have been the cause or causes of their formation, their action must have been regulated by this circumstance. For, that the stratum which out-crops on one side of a valley, and is found on the contrary side, occupying its exact position between other layers of strata, was at some former period a continuous and unbroken sheet, no one who has paid attention to the subject doubts for one moment.

The question therefore arises, by what laws of causation have these upper portions of the hydrographical basins of the Tyne, the Wear, and the Tees been formed?—what are the agencies which have removed one after another, such widely extended sheets of stratified rocks, until an aggregate thickness of not less than 1000 feet is cut through—whether by the streams which now flow down the sides and at the feet of mountains, or by the action of waves, when the land was slowly emerging from beneath the level of the sea; or by a series of cataclysms,—for no single flood, however violent, could produce such results.

Of the last hypothesis we shall only observe, that it is not easy to perceive how a series of broad floods, sweeping in certain directions across a country, could produce any orderly effects, unless it were to bring down all elevated objects, and reduce the surface of the land to a uniform level, the very opposite to the formation of valleys. But in the language of an able writer:—"Those who continue really to indulge in the visions which misled geology in its infancy, the dreams of universal cataclysms, and sudden creations, of a kind wholly remote from physical analogies, and to which it would be wrong to seek to apply physical explanations, so far place their speculations out of the pale of the inductive philosophy."*

Leaving out of consideration those cases where valleys are

* Powell's 'Essays on the Unity of Worlds,' p. 64.

formed on the line of immense fissures or dislocations, of which no instance occurs in Alston Moor, no other theories referable to causes now in operation, except the two former, have been proposed by geologists to account for the formation of valleys: —namely, the gradual abrasion and removal of the rocks, by pluvial and fluvial agencies, or by the action of breakers and oceanic currents; the abraded matter being carried away by the latter, and spread out upon the bottom of the sea.

The quantity of matter that has been removed is truly enormous. After a careful examination of the district, no one can doubt that the Millstone Grit which caps the mountains must have existed an unbroken sheet over the valleys of Alston Moor. There is, however, reason to suppose that upon these must have reposed the Coal-measures. Certainly, on the north side of the Ninety-fathoms dyke, the Newcastle coal-field is found thrown down, and lying opposite to the Millstone Grit or the upper part of the Mountain Limestone; which renders it conclusive, that a portion of the former at least was superimposed upon the latter at the time of the formation of this great dyke.

Setting aside the considerations respecting the denudation of the Coal-measures, it is difficult to conceive that the removal of the Millstone Grit, and such a great thickness of the Mountain Limestone, could be effected by pluvial and fluvial forces—by rain, floods and frost, or other decomposing atmospheric agents, no matter how long continued. Indeed, it is questionable whether such effects could be produced by these agents, during the longest cycle of those changes of level sustained by the solid matter of the globe—cycles which have been ever recurring, since the lowest sedimentary rocks were thrown down, up to the latest deposits which are now taking place at the bottom of the sea: the length of each being in all probability determined by some unknown laws.

The erosive effect of the waves and currents of the sea upon stratified rocks, appears calculated to form wide extended plains, and very gentle slopes around elevated tracts of sea-bottom. In some countries these effects are well distinguished from those resulting from pluvial and fluvial forces. Mr. Catlin observes, that "the summit level of the great prairies, stretching off to the west and the east from the river (Missouri) to an almost boundless extent, is from two to three hundred feet above the level of the river, which has formed a bed or valley for its course, varying in width from two to twenty miles. This channel or valley has been evidently produced by the force of the current, which has gradually excavated, in its floods and gorges, this immense space, and sent its debris into the ocean."* The rocks which form the surface of these wide extended plains are silicious limestones and Greensand Marl, corresponding to the Upper Cretaceous rocks of Europe.

The general features of such wide and comparatively level river basins as the Mississippi, may have been, and probably are at the present time in the course of being, modified by very slow elevations and subsidences produced by subterraneous forces. The erosive effect of streams in such countries will, however, in every case be readily distinguishable from the effects of the former, as deep channels grooved out leaving steep and precipitous banks. Indeed such appears to be an invariable law of running water, and especially so when the rocks are very hard, and a considerable inclination in the direction of the streams.

This tendency of water to cut for itself a deep and narrow channel whenever it flows over steep inclinations, applies equally to the mightiest rivers as to the puniest streams. Sir C. Lyell observes that "the Falls of Niagara afford a magnificent ex-

* 'North American Indians,' vol. i., p. 19.

ample of the progressive excavation of a deep valley in solid rock. That river flows over a flat table land, in a depression of which Lake Erie is situated. Where it issues from the lake it is nearly a mile in width, and 330 feet above Lake Ontario, which is about thirty miles distant. For the first fifteen miles below Lake Erie the surrounding country, comprising Upper Canada on the west, and the State of New York on the east, is almost on a level with its banks, and nowhere more than thirty or forty feet above them. The river, being occasionally interspersed with low wooded islands, and having sometimes a width of three miles, glides along at first with a clear, smooth, and tranquil current, (falling only fifteen feet in as many miles, and in this part of its course resembling an arm of Lake Erie. But its character is afterwards entirely changed; on approaching the rapids, where it begins to rush and foam over a rocky and uneven limestone bottom, for the space of nearly a mile, till at length it is thrown down perpendicularly 165 feet at the Falls. Here the river is divided into two sheets of water by an island, the largest cataract being more than a third of a mile broad, the smaller one having a breadth of 600 feet. When the water has precipitated itself into an unfathomable pool it rushes with great velocity down *the sloping bottom of a narrow chasm* for a distance of seven miles. This ravine varies from 200 to 400 yards in width from cliff to cliff, *contrasting*, therefore, *strongly in its breadth with that of the river above.* Its depth is from 200 to 300 feet, and it intersects for about seven miles the table-land before described, which terminates suddenly at Queenstown in an escarpment or long line of inland cliff, facing northwards towards Lake Ontario."* It will be observed that the St. Lawrence river must have flowed equally long in that portion below

* 'Principles of Geology,' p. 214 (ninth edition).

Lake Erie, where it is nearly level with the flat country on each side of its banks, as in the other portion, where it has cut out a deep gorge;—the difference of effect produced in the latter case being entirely owing to the greater inclination of its bed.

Probably the most striking illustrations of the excavating power of water in cutting passages through the hardest rocks are to be found in volcanic districts, where the sides of the mountains are often very steep. Though some of the deep ravines in such regions may have been originally shaped out by subterranean convulsions, and indicate the line of chasms or wide fissures, yet many clear instances of the erosive power of water do exist. Some beautiful examples of this character are given in Mr. Scrope's 'Volcanoes of Central France.' One of the most picturesque is a scene in the valley of Montpezat Ardêche, where lava has been poured out in sufficient abundance to fill the valley in some places entirely, and to an average depth of perhaps 150 feet, and a width of nearly half a mile. The mass of Basalt thus deposited, as well as the subjacent Granite, have been since cut through to depths varying from 100 to 200 feet, by the powerful action of the rivers whose channels the Basalt usurped.* In the same district of Central France Sir C. Lyell observes, that on the western side of the Puy Rouge, near Clermont, a powerful stream of lava has issued and flowed into the valley of the Sioule. The river has since excavated a ravine through the lava and subjacent Gneiss, to the depth of 400 feet.†

The least erosive effect produced by water is at the summit of mountains; as it descends it flows into channels, where it gra-

* 'Geology and Extinct Volcanoes of Central France,' p. 187.
† 'Manual of Geology' (fourth edition), p. 427.

dually accumulates and its power for the disintegration and transportation of rocks is much increased; its effects in this respect being proportional to the quantity of water and the amount of inclination of its bed. The effect produced by the small streams of Alston Moor must bear some resemblance to the steep valleys of erosion in volcanic districts. On the east side of the Tyne a steep escarpment, often precipitous, is formed by the basseting of the Scar Limestone. Whether this stratum has formed the banks of the river at some former period we shall not now inquire. The Ashgill, after flowing with a gentle inclination from the south-east, falls perpendicularly over this stratum of limestone before mingling its waters with those of the Tyne; a beautiful cascade or waterfall, some 70 feet in height, is the result. It is evident, that the increased velocity of the water at this point, has enabled this small stream to cut itself a passage not less than 90 or 100 feet deep for a considerable distance through the Scar Limestone and the rocks below.

The following sketch, Plate VI., represents this waterfall. As at the Falls of Niagara, the limestone reposes upon shale, which decomposes more rapidly than the former: the consequence is that the limestone projects sufficiently to protect a terraced passage behind the falling water, formed upon some grey beds of soft sandstone interposed in shale.*

* No place can be more cool and refreshing than this during a hot summer's day. The falling water, which is dashed into foam and spray among the huge blocks of limestone lying in confused masses below, conveys an uncommon, but not a disagreeable sensation. The summits of the rocks, and the sides below the waterfall, are planted chiefly with larch fir: and I cannot but agree with Wordsworth's opinion respecting the unpicturesque character of this species of fir for the decorations of such situations. At the bottom of the sketch is shown the ruins of some old washing floors, and one of the entrances into the Ashgill Field lead mine, both on the right side of the waterfall. At the time when these washing floors were made, large blocks of limestone had to be removed, and the horns of deer were found mixed with the small rubble and decomposed shale below. It is said that the hills of Alston Moor formerly abounded with wild deer,

Garrigill Burn has also evidently cut itself a passage of considerable extent through the Six-fathom hazle, and afterwards forms a small waterfall over the Slaty hazle. Here, as at Ashgill Field, the rocks cut through and forming the sides of a deep gorge rise considerably above the waterfall. Taking into consideration the small yearly impression this stream makes upon the hard rocks forming its bed, one cannot but be struck with the enormous length of time, which must have elapsed, before it could produce the effect which is so evidently due to its action. In a field on the north side of the burn, a former bed of the stream may be traced; it is now thickly covered with rich soil, and in some places to the extent of several feet; indeed the subsoil of the fields lying on the north side of the burn, between the waterfall and the Tyne river, is composed entirely of gravel and water-worn stones, the debris left by the stream at former periods. A number of years ago, while a labourer was digging in this locality, he found a large stone shaped like a watch-glass; it was lying about 2½ or 3 feet below the surface, the convex side being upwards. Below this stone were found pieces of water-worn pebbles and sand, clean and fresh as if they had been washed and left by the stream only the previous day.

Higher up on the mountain side Garrigill Burn has cut a passage through the Four-fathoms Limestone and Nattrass Gill hazle

which did not totally disappear until about the year 1760.* The precipitous scars rise considerably above the top of the waterfall on each side of the stream. On the Priorsdale side there is a passage through the limestone, leading to their summits. This passage is called the "Faerie Hole." From the rocks, at the termination of this passage, the view below is very impressive, and had care been taken in planting suitable trees in proper situations at the bottom and summits of the rocks, leaving open spaces from the road leading into this deep glen, it would have rendered the place sufficiently romantic for a wood scene in a "Midsummer Night's Dream."

* Hodgson's 'History of South Tynedale.'

deeply into the stratum of shale below. Still higher up it has formed a narrow gorge in the Great Limestone. It has also formed a deep glen in the plate bed below the Firestone and strata below to the top of the Coal Sills. The erosion of deep glens, however, is not confined to the Ashgill and Garrigill Burns. In some parts of their course it is found connected with all the minor streams of the country, the depth and extent being proportional to the quantity of water and the steepness of the mountain sides.

It needs scarcely be observed that the inclination of the bed of the Tyne is less rapid than its tributary streams. At Tynehead, above the point of its junction with Clargill Burn, the inclination of its bed is very rapid. The quantity of water flowing in it does not exceed that of some of the minor streams; its erosive effect in this part of its course is therefore similar and of equal amount; for, from Clargill Burn it has hollowed out a deep glen, which extends to the Great Sulphur vein. This vein throws up the Whin Sill above the present bed of the river; and since the formation of the deep glen the water has worn out this hard basaltic rock for about 66 feet on the south-west side of the vein, and is now precipitated over it, forming a waterfall of no great beauty. From this waterfall the water has hollowed out a narrow gorge in the same hard rock extending to Tynehead Smelt mill.

Above Tynehead Smelt mill a deep glen extends to Dosey lead mine. No doubt can be entertained but that its formation is due to the erosive action of the Tyne river, which at this point has dwindled to a very small stream. The Whin dyke has evidently formed a barrier; it is now, however, completely cut through. Allan's Cleugh branches from the Tyne on the east side, and a little above the Smelt mill it is a very deep gorge, formed so recently that its sides are very little grassed over.

This cleugh must owe its formation to floods and the working of Allan's Cleugh lead vein, since the quantity of water flowing in it is very small. Unlike any other stream in Alston Moor, it is formed on the line of one of the lead veins, and chiefly in a thick bed of shale.

A deep glen is formed by Black Burn and Shield Waters, extending from the Tyne river to Cashburn Force, its total length being about 4½ miles, and the aggregate thickness of the strata through which the water has cut its passage probably not less than 120 feet. As the inclination of the bed of this stream is by no means rapid, the length of time necessary for such a small body of water to wear down and remove such a large quantity of hard rock exceeds computation. At the Great Sulphur vein the stratum of basaltic rock is placed above the bed of Shield Waters, which stream has excavated a passage in it to a greater extent than that at Tyne head. Cashburn Force is formed by the water falling over this stratum of hard rock, and the scenery on the south side is similar to that at Tyne head, being wild and barren in the extreme.

It may be observed that the stratum of basalt which occasions these waterfalls, is the same which forms the bed of the Tees about 15 miles from its source, occasioning likewise the more celebrated waterfalls of Tees Force and Cauldron Snout. In both these places deep gorges have been excavated below the waterfalls, the sides of which are frowning tower-like cliffs, reared above the foaming waters dashing along their rocky bed below.

That the bed of the Tyne river is in the course of being gradually lowered, there can be no doubt. Below the village of Garrigill, and during the last century, it has lowered its bed several feet. At one place, stone warrens, built to prevent the land from being destroyed by the river, are now in the middle

of a meadow field; and it is remarkable, that the land which those warrens were intended to preserve is situated upon former beds of the stream at a still higher position. Should the bed of the Tyne continue to be lowered considerably, then, all trace of these former beds must be obliterated by the falling in of the banks, to be removed by the action of the stream. The village of Garrigill is built upon an ancient bed of the Tyne river, several feet higher than that upon which it is flowing at the present time.

Indeed, if such large quantities of matter have been eroded and carried away by the minor streams, we are justified in concluding, that a still greater amount of erosive effect must have been produced by the collected waters of those streams. Viewing it in this light, it is difficult to resist the inference, that the bed of the Tyne river above Alston must have been some 200 feet higher than it is at present. Its elevation to this extent would give the country a flatter appearance, and would materially diminish the rate of inclination of that portion of the minor streams situated near to the bottom of the valley. It is also evident, that those deep gorges in the Scar Limestone and strata below, which we have attempted to describe, could have had no existence, until the waters of the Tyne had cut a passage through the same series of beds in which they are formed.

While, therefore, little doubt can be entertained, that the bed of the river was at a former period considerably elevated above its present position, there are less clear indications of its occupying still higher positions during periods yet further removed from the present. We are not, however, justified in concluding, from a mere negation, that the erosive effects of the river commenced at the point where we cease to trace its action. The evidences of the work of denudation are defective, because it is the nature of every destroying cause to obliterate the signs of

its own agency.* As the river deepened its channel, and the sides of the hills were decomposed and carried away by pluvial agency, all marks of ancient river beds must have been destroyed.

As all traces of ancient river beds on the sides of the hills, if they ever existed, must have been obliterated long ago, it may be inquired if any trace of ancient sea beaches can be found in still higher positions. Some geologists have concluded, that distinct indications of them may still be traced on the line of outcropping of a few of the thickest beds of limestone and sandstone. It is, however, questionable whether proofs of their existence of a very decided character can be established. Such rocks must resist the decomposing effects of meteoric agency more effectually than the softer shale; and the effect of breaker action and atmospheric agency, must, under such circumstances, be difficult to distinguish.

It is now well established that before the elevation of the land to its present position, a period occurred, during which the temperature of the air was much lower than it is at present. During the summers of this cold period large masses of ice, such as avalanches and glaciers, descended from elevated lands; other masses were broken from the ice-bound coast, and floated by the winds and currents to other localities. In these drifting icebergs large masses of rock were frequently embedded and thrown down by the stranding or melting of the ice. In this manner, the Shap granite has been scattered far and wide across the valley of the Eden, and is now found on the western side of Cross Fell, elevated about 1800 feet above the sea. None of these erratic boulders passed over that portion of the Penine range of mountains, forming the western boundary of the upper

* Lyell's 'Principles of Geology,' p. 154.

part of the hydrographical basin of the Tyne; the evidence that might be derived from their position on the sides of the hills, respecting the amount of stream erosion effected since that period, is therefore wanting.

The absence of these boulders in the upper part of the Tyne basin leads us to infer that, at that period, the summits of this part of the Penine range of mountains were elevated above the sea, forming a narrow island; and this inference is confirmed by the fact, that these boulders of Granite have floated over, and been stranded upon the less elevated portion of Stainmoor, and are also found scattered far and wide over the low lands of Yorkshire, even to the coast of Holderness.

But if the more elevated portions of the Penine range of mountains existed as a group of islands, constituting the whole of the dry land, during the glacial period, all the rest of the country being submerged beneath the sea, it is manifest, that masses of rock might be embedded in ice, and floated from them in the same manner as the Wastdale head and Shap granite. Many blocks of sandstone are found in Alston Moor, in positions not easily accounted for, but which may be due to this cause. Unfortunately, from the similarity of sandstones to each other, the evidence that such has been the case is inconclusive.

On the top of Noonstones there are large quantities of quartz scattered upon the surface, with scarcely any covering of moss or other kinds of vegetation. These blocks of quartz are due to the denudation of the Great Sulphur vein, its great width at this point being almost entirely filled with this substance. The quartz is very compact and solid; its appearance is also peculiar and different from the quartz deposited in the veins on the east side of the Tyne. Quartz which cannot be distinguished from it, is, however, plentifully embedded in the Alluvial clay at Black Ashgill head, and not situated near any of the mineral

F 2

veins. It is also found scattered in large lumps on the hill separating Littlegill Burn from the Tyne river in a direct line from Noonstones to Black Ashgill head. In this locality there are no veins sufficiently strong or wide to contain it in such large masses. Indeed, so strikingly similar are the pieces of quartz found at Black Ashgill and below Arlo hill to those scattered upon the surface at Noonstones, that the conclusion is forced upon the mind of their having been transported from the latter to the former places by floating ice.

If this conclusion is correct, it necessarily follows, that the sheets of strata, which once stretched from the more elevated sides of the mountains across the valleys far above the bed of the present streams, were gradually removed by the action of the waves and currents of the sea; and further, that previously the strata had been thrown out of their original horizontal position, the erosion being regulated by those portions which were most elevated on the range of the Penine mountains, and by the anticlinal axis stretching east from the summit of Cross Fell to the source of the Tyne, and from thence north-eastward to Kilhope Law. The exact point, however, where breaker action ended, and the erosive action of the streams now flowing in the country began, is not perhaps determinable.

CHAPTER III.

OF THE LAWS WHICH REGULATE THE FORMATION AND DIRECTION OF VEINS.

It is remarkable, that in no case do the streams of Alston Moor flow upon or in the line of the great Cross Veins; nor does it appear that the existence of the latter have ever influenced even the direction of the former. The bed of the Nent river, in the upper part of its course, is formed upon strata elevated considerably above the same beds on the east side of Carrs vein. Above the village of Nenthead, the Nent crosses Carrs vein at an acute angle, but its direction is not in the least degree altered, and, between this vein and Foreshield Burn, the direction of this stream does not vary much from a direct course, which, as pointed out in the preceding chapter, nearly corresponds with the direction of the general dip of the strata.

It will also be observed upon the map, that no stream flows upon or in the direction of the Great Sulphur vein. On the contrary, in that part of its course between Duffergill and Cashburn, its existence is marked on the surface by a series of low mounds consisting of quartz mineral. It does not appear that this powerful vein has ever modified the direction of even the smallest streams. The same remarks are applicable to the east and west veins. Browngill vein—the strongest east and

west vein in Alston Moor—dislocates the strata at least 80 feet. Yet no indication of this vein is found upon the surface. The hills are rounded off without any apparent modification of their outline. Generally it is only where the streams have worn a channel in the solid rock that veins appear at the surface.

Had these powerful veins been formed at the same time that the land emerged slowly from beneath the sea, and when the principal portion of the valleys was scooped out by denudatory forces, it is not easy to conceive otherwise than that the unequal elevation of the strata, consequent upon their throws, would have modified the action of those forces, so as to connect the direction of the veins with certain lines of least denudation. Such, however, is not the case; no matter how great the amount of displacement of the strata, the form and outline of the hills are seldom if ever affected by it. Two questions therefore arise: Under what conditions were they formed, and at what period with relation to other geological changes which have affected the structure of the district?

The formation of mineral veins is considered by some geologists as the result of two very opposite causes. The formation of one class is supposed to be the result of the shrinking of the enclosing rocks during their consolidation from a semi-fluid state, or from their cooling down from a higher temperature than they at present possess. These are called veins of segregation. Another class of veins is considered to be simply fractures, formed at the time when the rocks forming their sides were elevated into the position they *at present* occupy. In this class of veins, the strata composing the sides or cheeks (as they are called by the miners of Alston Moor) are displaced, in some cases only a few inches, in others many hundreds of feet.

Of the former class of veins none are found in Alston Moor,

or if they exist cannot be distinguished from joints, and never contain lead ore. Joints found in the limestone strata of this district not unfrequently contain carbonate of lime. The appearance of this mineral when found in such situations is very different from the carbonate of lime deposited in mineral veins. In the former case it is chiefly found in amorphous masses without cleavage, breaking with a conchoidal fracture. Carbonate of lime, when deposited in the veins of Alston Moor, is generally crystallized in some or other of the numerous forms of which this mineral is susceptible, except in some instances where the veins are filled with calc spar, which then, however, possesses a very distinct cleavage.

The hypothesis of veins having been formed by the shrinking of the rock during its consolidation, has perhaps arisen from some supposed analogy to the cracks formed during the induration of clayey matter by the heat of the sun. There is, however, very little analogy between the two cases. Sedimentary rocks have been consolidated under the bed of the ocean by immense pressure. A mass of clay, consolidated under a pressure of some hundreds of thousands of pounds per square foot, is not likely to contain many cracks or fissures. Viewing the subject in this light, it appears absurd to suppose that any shrinking of a mass of sediment could take place under such conditions, so as to cause the formation of fractures at right angles to the beds, and possessing a longitudinal direction. The consolidation of a semi-fluid or pasty mass under immense pressure, would be simply to diminish the thickness of each stratum without causing any fracture whatever.

Adits and other mining works made in soft shale generally contract their dimensions, their sides in a long course of time being sensibly pressed nearer each other; and when water is drained from harder rocks of limestone and sandstone there is

no tendency to form cracks and fissures by the shrinking of the mass. The contrary perhaps always takes place; for many old miners suppose that works made even in very hard rock slowly contract their dimensions.

Mr. Phillips observes that "it is certain that in the limestone dales of the north of England mineral veins are sometimes directed along the master joints of the rocks."* A glance at the map which accompanies this work will show that this cannot be the case in Alston Moor. I think that the formation of joints is due to a cause, whose action is limited to a very moderate depth from the surface, when compared with the depth to which veins extend. The *action* of the cause which has occasioned joints in hard rocks may have been regulated by a crystalline structure caused by heat, when the rocks were lying at great depths, under an enormous pressure of other rocks which have since been removed by denudation.† Limestone strata near the summit of mountain ranges, even when under considerable pressure, are found to contain more joints, and those of a more open character, than the same strata, lying in the valleys, at a much less depth below the surface. In the latter case, the texture of the rocks is also more compact and harder.

Some of the veins in Alston Moor dislocate the strata not less than 200 feet. On the thrown up side of one of these powerful veins, a limestone stratum near the surface is much broken with joints often filled with soft clay. On the thrown down

* 'Manual,' p. 543.

† There is scarcely any doubt that the force which is concerned in aggregation (of crystals) is the same which gives to matter its crystalline form: indeed a vast number of bodies, if not all, which appear amorphous, are, when closely examined, found to be crystalline in their structure: we thus get a reciprocity of action between the force which unites the molecules of matter and the magnetic force, and through the medium of the latter the correlation of the attraction of aggregation with the other modes of force may be established.—*Grove's Correlation of Physical Forces*, p. 189.

side of the same vein the same stratum of limestone is very compact. With the exception of very small fractures or leads connected with the veins, scarcely a parting can be found to denote even a crystalline arrangement into square masses. That joints are most numerous, as well as more open, near the surface must be acknowledged as a general law which in Alston Moor admits of no exceptions. In many instances, at a very moderate depth from the surface, they close up and almost cease to exist. The law is alike applicable to sandstones as limestones; the degree however varies—limestone rocks are most susceptible of joints, sandstones next, and shale the least.

It has already been stated, that sedimentary rocks have been consolidated under enormous pressure. The effect that would be produced by the removal of such pressure from extended sheets of hard rock is well worthy the attention of geologists. That some effect would follow no one can doubt; and especially, if the rocks subjected to such conditions should be traversed by numerous lines of weakness intersecting each other nearly at right angles. The question is, whether the particles composing the rocks would not have some tendency to spring upwards, and withdraw from each other in a horizontal direction; thus causing very small fissures corresponding to those lines of weakness. No matter how small such fissures might be at the first, they would gradually be enlarged by the percolation of water holding carbonic acid, &c. in solution. Limestone is more susceptible of decomposition by this acid than either sandstone or shale, and from its greater hardness it would probably be more susceptible of fracture; thus corresponding with the facts derived from observation. But whatever may have been the cause of joints, the facts we have advanced are indisputable. It is evident, therefore, that they must have been formed after the general configuration of the country was modelled by the removal of

large masses of rocks, which once filled up the present valleys, and, as we shall endeavour to prove, long posterior to the formation of veins. If mineral veins are directed along the joints of rocks, the coincidence of direction is merely accidental, and we may safely conclude, that joints have never in the slightest degree modified the direction of veins in Alston Moor.

The flats found connected with mineral veins in some of the limestone strata, when near the surface, are intersected with joints often filled with clay. Where such is the case, they cut through the seams of ore, spar, or the cavernous part of the flat left unfilled with mineral matter; nor is their direction modified in the slightest degree by the foreign substances so different from the general texture of the enclosing rock. The proportion of matter, introduced into a stratum by flats, often bears only a small proportion to the quantity of rock which has been left undisturbed in its original position: and although in many cases it has undergone some chemical change, the lines of crystalline arrangement appear not to have been interfered with. Hence, when the joints were formed, the forces seem to have been sufficiently powerful to break through the foreign matter introduced into the heart of the stratum; thus tending to support the conclusion, that joints were not only formed after the veins, but subsequently to the deposition of the mineral substances they now contain.

If the mineral veins of Alston Moor are considered due to subterranean forces; before we can establish the period of their formation, in relation to that of other geological phenomena, it is necessary to inquire, in the first instance, whether their formation and direction are regulated by any law.

In their direction and mineralization very distinct characteristics arise, upon which a classification may be founded separating them into three distinct kinds.

The first class comprehends the east and west running veins; their direction however varying between N. 60° E. and S. 60° E. magnetic. These veins are generally well mineralized; and metallic substances may be found in them when their sides are formed of any of the hard strata of limestone and sandstone. The second class comprehends the veins running in a north and south direction. This class of veins varies its direction much less than the east and west veins. In the strata above the Great Limestone they seldom contain metallic substances, and indeed very little vein mineral of any kind. Much lead ore has been produced from them in the Great Limestone: and both *lead and copper* ores in the strata below. Both these classes of veins are intersected by another class, of small veins, traversing the country in two directions, the one being about S. 55° E. the other about S. 55° W. magnetic. Like the second class of veins, they contain little vein mineral in the strata above the Great Limestone. In the strata below, they seem to be filled with copper and iron pyrites, salts of lime, &c., but very seldom contain lead ore either in limestone or sandstone. Those having a south-easterly bearing are probably more numerous than the others.

We have observed above, that these veins are weak. The Great Sulphur vein forms, however, a remarkable exception in this respect; as well as in the extraordinary quantity of vein mineral it contains, chiefly quartz and iron pyrites. But on account of its great width and mineral character, so totally different from that of any other vein in the district, it may be well to consider it *sui generis*. When compared with the other veins in Alston Moor, the width of this vein is indeed very remarkable. Its exact width is not so well defined at Cashburn and the Tyne, as it is at Crossgill, where it is not less than 300 feet, and presents the appearance of originally having

been a very wide fissure, the sides of which coming together, occasioned the formation of a series of parallel fissures; all of which have subsequently been filled with quartz and iron pyrites.

Following the direction of this vein from the north-west to the south-east, it will be perceived that the character of its mineral varies in different localities. At Cashburn, it is chiefly filled with quartz not much crystallized. In a portion of ground between Cashburn and Crossgill, its direction is indicated by a number of low round hills, consisting chiefly of quartzose mineral, which apparently has resisted the decomposing influences of atmospheric agency, more effectually than the rocks on each side. At Crossgill, in addition to quartz, it contains much iron pyrites, which is slightly auriferous; some of the weaker strings contain copper pyrites, which has not hitherto been found in quantities sufficient to repay the cost of mining. On the top of Noonstones, its great width is apparently entirely filled with quartz. At the Tyne river it contains less quartz, and that of a more impure character; and at Darngill Bridge, the character of the vein does not seem to differ much from the strong east and west veins in the district. The quartz has almost entirely disappeared, and the vein is filled with douk where plate or shale forms its sides.

No mining works have been made to prove any of the east and west veins at the point of intersection with this powerful vein. All those veins, however, exist on opposite sides of this vein apparently not much changed in their strength and other mineral characteristics, which I think can only be explained on the supposition that the Great Sulphur vein is of posterior formation. Mining works were made in the point of intersection between Sir John's vein and the Great Sulphur vein, and I am informed that all trace of the former vein was lost in the latter. After continuing the works on the line of Sir John's vein, to

the south-west side of the Great Sulphur vein, the former was found shifted about 20 fathoms. This is easily accounted for, without supposing any shifting of the strata in a horizontal direction. In the strata below the Scar Limestone Sir John's vein hades very rapidly to the east, so much so that in Leehouse Well mine the difference between the position of the vein in the Scar Limestone and its position in the Six-fathoms hazle is not less than 37 fathoms,—that is, the vein in the Scar Limestone is lying not less than 37 fathoms on the west side of its position in the Six-fathoms hazle. In Stow Crag mine the hade appears to be much less than this; but, like most of the cross veins in Alston Moor, it must have a considerable one. Now, on the supposition that the formation of the Great Sulphur vein is posterior to that of Sir John's vein, it is evident, that a vertical displacement of the strata some 30 fathoms by the former must place the latter in the lower stratum of limestone, in a position west of the point where it entered the Great Sulphur vein on the contrary side in the Six-fathoms hazle; or in other words, the shifting must equal the hade of Sir John's vein, in the strata comprehended in the throw of the Great Sulphur vein. From this circumstance, I apprehend, that the formation of the Great Sulphur vein is *posterior* to that of the cross veins of Alston Moor.

On the south side of this vein a whin dyke traverses the country nearly in a parallel direction. No displacement of the strata takes place. It seems to have been a simple opening or fissure, glutted with melted matter, as soon as the opening or rent was formed, no time intervening to allow the sides of the fracture to fall in. It is magnetic. A theodolite, furnished with a delicate needle, was, during a survey, placed near it, when the needle was deflected from its proper position $1\frac{3}{4}°$. Mining works were made in it at the point of its intersection with Doukburn vein. No trace of the vein was found in the dyke; but

after the latter was cut through, the former was found in its proper position or bearing. We are therefore justified in inferring that the Whin dyke is of later formation than the metallic east and west veins of Alston Moor.

It may be observed that if there is any law regulating the formation and direction of veins, it will be best traced in the phenomena connected with those which are the strongest.

We have already pointed out the direction of the dip of the strata on the west side of the Tyne river as being nearly at right angles to the general direction of that portion of an anticlinal axis comprehended between the Tyne river and the summit of Cross Fell. It will be observed upon the map, that the direction of the Great Sulphur vein is parallel to this axis, and as the strata on the south-west side are elevated some 180 feet, it would appear that the vein is simply a fracture and displacement of the strata; which may be illustrated by the annexed figure.

Let A B represent a series of rocks, stratified and of indefinite thickness, as originally deposited horizontally at the bottom of the sea; now, if these sheets of rock are raised by elevating forces at C, or, the depression of A^2 B^2 to B A respectively, the strata must be subjected to a degree of tension, and should it give way, open fractures may be formed as at v^1 v^2. From this simple diagram it is easily seen how the Great Sulphur vein has been formed by the fracture of the strata, resulting from the tension to which it was subjected when thrown out of its original horizontal position.

It will be perceived that on the east side of Darngill Bridge, instead of being parallel, its course is nearly at right angles to the anticlinal axis. No sooner does this take place, than the character of the vein is modified to suit the altered conditions; and this is effected by its ramification into different portions, those thrown off on the north side throw up the north cheek, thus neutralizing that of the other or south portion, and clearly proving that its formation and that of the anticlinal axis are connected in one law of causation.

This great vein cannot be traced on the contrary side of the hill, and doubtless ceases to exist as it approaches the anticlinal axis.

The remarks on the Great Sulphur vein apply also to the Whin dyke, the only difference being in the amount of displacement of the strata, which in the latter is scarcely perceptible. No trace of this dyke can be found in Crook Burn. It may be supposed that it gradually closes and ceases to exist, before it reaches the anticlinal axis. If this can be proved to be the case, its formation is evidently due to the same law of causation as the Great Sulphur vein. The strata dip rapidly from the anticlinal axis on each side of this Whin dyke to the Great Sulphur vein, the dyke slightly modifying the rate of inclination, which is more rapid on the north side. Sir C. Lyell observes that ramifying dykes of trap pass through the fossiliferous strata at Markernd, near Christiania, in Norway, without deranging their strike or dip.*

If the formation of this dyke is connected in causation with the anticlinal axis—a supposition which seems to be highly probable—it is evident that it cannot be connected with the stratum of basalt, which occupies a certain and unvarying position, among the rocks of the district; and, consequently, is subjected

* 'Elements of Geology' (fourth edition), p. 446.

to all the dislocations and inclinations undergone by these. And further, the basaltic dyke must cut through the stratum of basalt, descending to vast depths, through its narrow passage, into which it was originally suddenly propelled and sustained by subterranean forces—a liquid, fiery mass, filling up the smallest interstices of the fissure, "*et pressa gravitate sui*" with all the force that an elevation of many miles could give; yet too light in the Plutonic balance, it solidified into the hardest stone, and remained in its narrow prison—a memento of forces, compared with which man's mightiest engines are mere toys and playthings.

CHAPTER IV.

OF THE LAWS REGULATING THE FORMATION AND DIRECTION OF EAST AND WEST VEINS.

AT Tynehead, the group of veins comprehended between Dosey and the Tees-side mines are mostly of small magnitude, dislocating the strata very little. With the exception of Providence veins, they all cease to exist as they approach the anticlinal axis in their course westward; and also in their eastward course several of them dwindle to nothing near the summit of Bel Beaver.

None of the veins between Calvert and Littlegill veins, including both, are remarkably strong. Some of them contain much sparry matter in the strata below the Great Limestone. In their direction eastward they all cease to exist, before reaching the anticlinal axis. Calvert veins forming Swarth Beck vein may be traced to the west side of the Penine range of mountains. Littlegill vein has also been traced, at several points, through the vale of the Tyne to the Cross Fell mines.

The next group are comprehended between Longman Hill and Hound Hill. On the west side of Rodderup Fell cross vein, none of the veins forming this group are strong. In their direction eastward they converge, and though most of them are

in existence at the Tyne river, further east they dwindle to nothing.

The most important east and west veins of Alston Moor are Browngill and Benty Field veins, including those which branch from the former.

It will be observed upon the map, that Benty Field vein is ramified into weak strings, on the south side of Rodderup Fell vein. At Dryburn these strings are collected, and a vein of considerable width is formed, which dislocates the strata perhaps not less than 60 feet. This vein continues strong, until it crosses Garrigill Burn, but from this point to Old Groves cross vein its width and throw gradually decrease. From this cross vein to the east boundary of the Alston Manor, it is a vein of uniform and moderate size.

On the west side of the Tyne river, and on the south side of Benty Field vein, two or three weak veins are found, which scarcely dislocate the strata to the extent of a few inches; though extensive flats are connected with them in the Tyne-bottom Limestone. On the east side of the Tyne, these veins combine, forming Browngill vein, which, in its course eastward, increases in both width and throw in proportion as those of Benty Field vein decrease. At the intersection with Garrigill Burn Old Groves cross vein, Browngill vein throws up the sun cheek not less than 60 feet. Still further east its throw is about 84 feet. At the intersection with Nunnery cross vein, the greater portion of this east and west vein takes the direction of the latter; but in its direction southward it rapidly decreases in magnitude, and is also apparently much broken into strings before it intersects Black Ashgill cross vein. The north portion also splits up, forming the Caple Cleugh and Middle Cleugh veins. Long Cleugh vein traverses the district in the direction of Browngill vein, but its throw at Carrs vein is only 10 feet. With the exception of

Middle Cleugh second sun vein, all the Caple Cleugh and Middle Cleugh veins cease to exist before reaching the east boundary of the Alston Manor.

It will be observed upon the map that several other veins besides those just noticed are thrown off Browngill vein. Briggle Burn is by far the strongest of these; this vein increases its width and throw as it approaches Carrs vein. After its intersection with this cross vein it is divided into two parts, respectively termed Rampgill and Scaleburn veins. After this separation, the former takes the direction of a quarter point vein, for about 180 fathoms, and then resumes its general bearing, in which it continues to the east boundary of the Alston Manor. At this point it ramifies; the principal portion being deflected to the south combines with Rampgill high sun vein. On the west side of this combination the latter is a weak vein, possessing only a few inches of throw. The direction of the Coal Cleugh east and west vein is nearly parallel to the anticlinal axis. In the Nenthead mines Rampgill vein displaces the strata about 18 feet; in the Coal Cleugh district about 36 feet, but after its intersections with the powerful Coal Cleugh cross veins, its throw is diminished to 15 feet, and this is counteracted by a north portion whose throw is about 8 feet north side up.

On the north side of Benty Field vein, the Cowper Dyke heads and Fletcheras veins are also formed from weak strings; and, on the west side of the Tyne river, traverse the district in a parallel direction. On the east side of the Tyne all these veins are deflected into a more northerly direction. Excepting Brownley hill vein the rest cease to exist before reaching the east boundary of the Alston Manor.

Near Garrigill Burn cross vein, Black Syke vein comes into existence and traverses the district near to and parallel with Fletcheras vein. Both of these veins are of very considerable

magnitude. Black Syke vein, however, throws up the north cheek nearly as much as Fletcheras vein does the south cheek, thus neutralizing each other's effects, and, as the hade of a vein in a downward direction is opposite to that of its throw, it is evident, that in such instances the two veins must become one, at no great depth below the surface.

Rodderup Fell vein throws up the north cheek about 15 feet. It is displaced in a longitudinal direction at the West cross vein; with this exception, its bearing between Shield Waters and Black Ashgill cross vein is very direct. At How Hill on the east side of the Tyne river, a strong portion bears off in a more northerly direction and wastes into very small portions or leads as it approaches Flough edge vein.

Flough edge and Nattrass Redgrove veins traverse the district in a direction parallel to Browngill vein, and from Redgrove vein a number of east and west veins split off the north side in a somewhat similar manner; with one or two exceptions all these dwindle to nothing in their course eastward.

The direction of Bayle Hill and Fistas Rake vein is nearly parallel to Rodderup Fell vein; both are of small magnitude. In the Blaygill mine the latter is moderately wide, but only dislocates the strata about three feet.

Thorngill veins traverse the district in the same direction as Browngill veins. These veins possess considerable strength. They enter into combination, and, as Lough vein in the Blaygill mine dislocates the strata not less than 24 feet. The direction of the Slote vein does not vary greatly from that of the Thorngill veins. It will be observed, that this group of veins differs from the Browngill and Nattrass Redgrove veins, in not being connected with a series of veins falling off on the north side.

In Alston Moor, the east and west veins generally throw up

the south cheek, and hade, dip, or strike from the surface in a contrary direction. In the following pages, whenever their throw is given, this fact will be understood, unless the contrary is expressly stated.

Such is a brief description of the principal east and west veins in the district. We shall now endeavour to prove, that their existence and direction are due to the tension to which the strata were subjected when thrown out of their horizontal position.

In tracing this connexion, we shall begin with the Browngill fissures: excepting the Great Sulphur vein, these are of much greater magnitude than any other east and west veins in the district. To whatever phenomena veins may be related in causation, the connexion will be most clearly seen where the greatest amount of effect is produced.

At the point where the two anticlinal axes join in Kilhope, and at the point where Rodderup Fell vein is intersected by the West cross vein, near Shield Waters, the beds are elevated to the same horizontal position. Between these two points is the general bearing of the great Browngill line of fissures; consequently this series of veins traverses the district on the level line of the strata, or in other words, it traverses the district nearly at right angles to the general strike of the beds on the south side of the fissure.

We have already pointed out, that between Black Burn and the higher part of Gilderdale Burn, the strata must be lying nearly horizontal, if the dip is not indeed in an opposite direction to that on the south side of the former stream. As this great fissure approaches the point where this change of inclination takes place, it suddenly breaks up into portions, so weak, that they have scarcely been noticed in the Rodderup Fell mine. Now in connexion with this circumstance, it is neces-

sary to observe that, had this powerful vein been produced westward, in the same direction, its relation to the dip of the strata would have been changed, and, instead of corresponding with the level line, there must have been a considerable acclivity of the beds in its direction towards the heights of Hartside.

At the east end of the course of this great fissure, its dependence upon the tension undergone by the enclosing rocks is equally remarkable. As it approaches the anticlinal axis, it breaks up into a number of veins which are deflected to the north. We may consider its full termination to take place at Carrs vein, where it is represented by Long Cleugh vein, which, as before observed, only dislocates the strata ten feet. Had this vein or fissure been prolonged into the Weardale district, there must have occurred a considerable declivity of the beds in the line of its direction. From the conditions connected with its terminations, a presumption arises that this vein is simply a fracture or opening in the rocks, and a dislocation effected by subterranean forces of elevation or depression, and is consequently dependent upon the unequal position to which the beds are raised.

Again, from the intersection of the axes of elevation in the Kilhope district, the beds rise in the direction of the east and west axis, and culminate between Burnhope Seat and Dowgreen, or the source of the Tyne river: from thence in its north-westward direction to Cross Fell Smelt mill they incline considerably. Now in their direction from the east to the west, the magnitude and throw of the Browngill fissures vary in the same or a corresponding manner. This vein or fissure exists in its greatest magnitude precisely opposite the point where the strata are most elevated on the line of the axis; and in proportion as the strata incline in each direction from this highest point of elevation, so do the magnitude and throw of Browngill

vein diminish; thus establishing a real correlation between the two kinds of phenomena, and proving that they are dependent upon the same laws of causation. Mr. Mill lays down as the fifth canon of his experimental method, "Whatever phenomenon varies in any manner, whenever another phenomenon varies in some particular manner, is either a cause or an effect of that phenomenon, or is connected with it through some fact of causation."*

The Browngill fissures are not only the greatest in magnitude, but also in extent, of those having a similar direction in Alston Moor. Now it may be pointed out, in connexion with these circumstances, that their position corresponds with a line which would form one of the diagonals of the trapezoidal-shaped district, bounded by the two anticlinal axes and the Birchy Bank vein on the north side of Black Burn, and precisely where the longest fissure could be formed without being prolonged into strata dipping in different directions from those on the south side of the vein.

But if the strata were subjected to the greatest amount of tension in the direction of the east and west diagonal of the trapezoid, it is evident that, subject to no other disturbing force, they would be subjected to the least tension in the direction of the other diagonal—a conclusion which corresponds with the facts of the case; for there are no veins of the slightest importance traversing the district in this direction.

Again, the Caple Cleugh and Middle Cleugh veins thrown off on the north side of the Browngill fissure, traverse the district on the level line of the strata; but they all terminate in their direction eastward. The east end of the Browngill fissure is deflected a little to the south; and it is remarkable, that a line

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* 'Logic,' vol. i., p. 435.

drawn on the general bearing of that portion where it exists in the greatest magnitude, coincides in a general way with the various points of termination. The existence of the north portions (in a part of the district, in which the strata dip in a different angle to that on the south side of the main fissure, and to which they conform in their direction), is dependent upon the same cause as the formation of the principal fissure.

In the Nenthead district, the Briggle burn veins traverse on the level line of the strata. In the Coal Cleugh district the beds incline a little in the direction of the veins eastward; and as they approach the Swinhope district their direction is not parallel to the axis: in this case they either terminate abruptly, or their throw is diminished, and in a great measure counteracted, by the formation of another vein on the north side, which dislocates the strata in a contrary direction.

Next to Browngill, Fletcheras vein is the strongest of its class in Alston Moor. It traverses the district on the level line of the strata. On the south side of the vein, and at the point where it crosses the Tyne river, and near to Carrs vein where it terminates, the beds are elevated to exactly the same horizontal position. Like the Browngill fissures, it wastes to nothing in its direction westward; it also dislocates the strata to the greatest extent opposite that point on the axis of elevation where the strata are the most elevated.

Except Crag Green sun vein, which terminates at Old Groves vein, no veins are thrown off on the north side of Fletcheras vein. In its direction eastward, where, as we have shown in connexion with Browngill vein, a dislocation of the strata is less necessary on account of the lower position, the strata are elevated on the anticlinal axis—it maintains its throw, which, however, is counteracted by that of Black Syke vein. In the Gallygill Syke mine, the latter vein throws up the north cheek

to nearly the extent that Fletcheras vein does the south cheek, thus producing an effect of the same kind on the strata as would have resulted from its breaking up into a series of weak veins, ultimately dwindling to nothing.

It is unnecessary to pursue the subject further. The other east and west veins of Alston Moor are related to the same phenomena as Browngill and Fletcheras veins—are dependent upon the same laws of causation, and were formed contemporaneously with them. Their magnitude is proportional to the intensity of the elevatory forces, as denoted by the effect upon the strata; and their direction varies as the dip, or, to speak more forcibly, *their magnitude and direction are proportional to the amount of twisting, or wrenching, undergone by the strata, when their horizontality was disturbed by subterranean forces, either of elevation or depression.*

We have shown in a previous chapter, that the denudation of the rocks in the district and the formation of the valleys were regulated by the axes of elevation, which form the boundary of this portion of the hydrographical basin of the South Tyne river. In this chapter I trust we have satisfactorily shown, that the formation and direction of the east and west veins are connected in causation with the formation of this axis—are, in fact, correlated phenomena—consequently, the veins must have been in existence before the removal by denudation of the rocks which once filled up the valleys.

But there appears to be grounds for concluding, that they were really formed at a period of time long antecedent to that of the formation of the valleys of Alston Moor. The Ninety-fathoms dyke traverses the country in a somewhat parallel direction, and is related to an unequal elevation of the strata in a manner similar to that of the metalliferous east and west veins of Alston Moor. It seems, therefore, probable that these veins

and the Ninety-fathoms dyke were formed contemporaneously. Professor Phillips observes that the Penine "fault is cut off to the north by the Ninety-fathoms dyke, and to the south by the Craven fault; and there is every probability that it is actually continued along the lines of these faults to a direction right-angled, or nearly so, to its own course. If this be so, and the whole is one complex dislocation, we may surely conclude that the middle portion, even if not of the same age as the extremes, was produced in the same manner."* There is one circumstance which is not connected with both faults. On the north side of the Ninety-fathoms dyke the beds of the Newcastle Coal-measures are found, but on the west side of the Penine fault there is no reason to support a conclusion, that across the valley of the Eden these coal-beds are reposing beneath the New Red Sandstone. The fact of the Coal-measures being found on the north side of the Ninety-fathoms dyke is sufficient to prove that at the time of its formation this series of beds was reposing upon the Millstone Grit and Mountain Limestone of Alston Moor. If the Coal-measures were deposited across the vale of the Eden, they were probably removed by denudation before the connexion of the Penine fault with upward movements of the strata lying on the east side.

Such are the facts, on which we may base the hypothesis of the formation of the east and west veins taking place before the removal of the Coal-measures by the currents of the sea or by breaker action, and which enable us to conclude, with great probability, that the east and west veins were in existence when the strata were lying at a depth of at least 5000 feet below the highest point of their present elevation.

In conclusion, it may be observed, that with the exception of

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* 'Manual,' p. 571.

a single basaltic dyke, there are no indications that the district under consideration has ever been subjected to volcanic agency of a violent or spasmodic character. It seems probable that the removal of the Coal-measures and the denudation of the valleys are due to causes much of the same kind as those now in operation on the earth's surface. If this is the case, the period of the formation of the east and west veins is separated from the Glacial epoch by immeasurable periods of time. We vainly attempt to lift the curtain and unveil the innumerable collocation of things and succession of events, which must have occurred upon the surface and in the interior of the earth from that remote period to the present time. Yet this vast series of changes was ordained and controlled by an infinite Intelligence, a Being who existed from everlasting, and who must regard the longest cycle which geology compels us to assume as but "a point of time, a moment's space," when contrasted with those vaster periods which have transpired since His fiat called matter into existence, and impressed it with laws which cannot be broken;—since He began to evolve the phenomena of the universe by a linked succession of causative events.

The contemplation of these affords us the most sublime enjoyment, and brings us into closer communion with their great Author.

"A presence that disturbs me with the joy,
Of elevated thoughts; a sense sublime
Of something far more deeply interfused,
Whose dwelling is the light of setting suns,
And the round ocean and the living air,
And the blue sky, and in the mind of man:
A motion and a spirit, that impels
All thinking things, all objects of all thought,
And rolls through all things."

Wordsworth.

CHAPTER V.

OF THE LAWS CONNECTED WITH THE FORMATION OF THE CROSS VEINS OF ALSTON MOOR.

THE cross veins are the next class which comes under consideration. They traverse the district in a direction about 30° east of south, true meridian, and their general bearing is more uniform than that of the east and west veins.

Veins traversing the lead-mining district in this direction are found of all degrees of magnitude. A displacement of the strata to the amount of 260 feet is found connected with Carrs vein in some parts of its course, while Cowhill cross vein dislocates the strata only a few inches; but the throw of each particular vein varies greatly. In the strata above the Great Limestone few of them contain sparry vein minerals; it is more especially when this limestone forms their sides that they are found to contain such kind of minerals. In this respect they differ very much from the east and west veins; but in the Great Limestone the width of the veins varies much. In some parts of any particular vein large quantities of mineral are found, while in others, little removed from the former, they contain scarcely any, being chiefly filled with douky matter. The mineral contents of the east and west veins are generally harder and more compact than those of the cross veins. These simple facts are sufficient

grounds for placing the cross veins in a separate class, and the propriety of so doing will appear during the investigation.*

In the first instance we shall attempt to give a short description of the principal veins of this class traversing the mining districts of Alston Moor and Coal Cleugh, commencing with those found in the latter district.

The Coal Cleugh east cross vein is the one situated furthest east in the district represented upon the map. This cross vein throws up the east cheek about 96 feet. Another vein is found at a short distance further west, which throws up the west cheek about 88 feet. The throws of these two veins in a great measure neutralize each other, and at no great depth below the surface the two must hade to each other and become one vein. Their direction is nearly parallel through the whole extent of the Coal Cleugh and Kilhope districts, but in their course southward the West cross vein becomes much stronger, and in the latter district dislocates the strata not less than 120 feet.

About 220 fathoms further west, another vein is found, called Pump Sump cross vein. It is a vein of less magnitude than the last, and throws up the west cheek about 36 feet. I think it not improbable, that this vein is identical with the Longhole head vein of the Kilhope district. About 80 fathoms west another weak vein is found, which throws up the west cheek about 4 feet.

The Bounder end cross vein is the next in order of succession. It dislocates the strata very little. But for the extensive flats of lead ore which have been found on each side near its intersection with Rampgill vein it would have been considered as of no importance whatever.

* Where a certain apparent difference between things (though perhaps in itself of little moment) answers to we know not what number of other differences, pervading not only their known properties, but properties yet undiscovered, it is not optional but imperative to recognise this difference as the foundation of a special distinction.—Mill's 'Logic,' vol. i., p. 137 (fourth edition).

Proceeding further west into the Nenthead district, the first vein of importance is Rampgill and Scaleburn cross vein, whose throw is only 4 feet east side up. It is, therefore, a vein of small magnitude, although very considerable quantities of lead ore have been produced from it, especially on the south side of Rampgill, and on the north side of Scaleburn veins. In its course northward, this cross vein enters into combination with the east portion of the group of powerful cross veins which traverse the rocks of Alston Moor on the east side of the Nent river.

In the Haggs mine, all these cross veins are comprehended in two—Carrs vein and Wellgill cross vein; the former throws up the west cheek, the latter the east cheek; in consequence they must hade into each other, and become one vein at no great depth from the surface. In their direction southward through the Nenthead mining district, these veins are ramified; the east and west portions dislocating the strata in opposite directions, and hading to each other in a downward direction; but as the different portions approach the anticlinal axis they nearly all throw up the west cheek and hade in the usual manner to the east. The dislocations of the strata at these cross veins may be seen on Plate VII.

On the west side of Carrs vein, and situated no great distance from it, two cross veins are found, neither of which possesses much throw. In its direction northward, Cowslitts cross vein dwindles to nothing. On the south side of Long Cleugh vein, Cowhill cross vein, is found considerably stronger than on the north side of that vein. It throws up the east cheek from 12 to 18 feet; and probably continues to do so, in its direction southward.

The next vein, in the order of succession, is Black Ashgill vein. On the north side of the Caple Cleugh veins, it is of great magnitude, dislocating the strata not less than 60 feet; the east cheek being thrown up. On the north side of the

Dowgang veins it is found ramified into several portions; their throws, however, scarcely displace the strata 30 feet. Between the Grassfield and Hudgill Burn mines, it is a vein of moderate strength, and exists in two portions situated at no great distance from each other. Northward from Hudgill Burn, it gradually diminishes both in width and throw. In the Foreshield mine, it is found in two portions, neither of which possesses much magnitude. On the north side of Blaygill Burn it diminishes to a mere string, with little or no throw.

On the south side of the Caple Cleugh veins its throw does not exceed 40 feet. It diminishes rapidly, on the south side of its intersection with Black Ashgill east cross vein. In Priorsdale, its throw does not exceed 6 feet; and it does not at all seem improbable, that, in its direction further south, it dwindles to nothing. Black Ashgill east cross vein, however, increases both in magnitude and throw. It throws up the west side, and near the anticlinal axis its throw is considerably more than in the Black Ashgill lead mine.

Near the intersection of Black Ashgill vein with the Dowgang veins, two weak veins are formed on each side of the former vein; the one passes through the Hudgill Burn lead mine, the other crosses the Nent river; both cease to exist in their direction northward.

The next cross vein of importance is Garrigill burn or Old Groves vein. On the south side of Browngill vein, it is found in two portions, both of which are weak, and like Black Ashgill cross vein, probably dwindle to nothing, in their direction southward. Northward from the Browngill veins, it gradually increases in magnitude, until it intersects with Fletcheras vein. From this point it gradually diminishes, and ceases entirely to exist before reaching Nattrass Gill.

Windshaw Bridge is another cross vein, whose direction for a considerable distance corresponds with that of the Tyne river.

This is a very weak vein, its throw being not more than 18 or 24 inches east side up.

On the south side of the Great Sulphur vein Sir John's cross vein exists, and is ramified into two portions which rapidly separate from each other. It is also split into two portions on the north side of Crossgill. It is a very wide vein at the point of intersection with Rodderup Fell vein in the Slaggy Burn mine. At Gilderdale and Thornup Burns, both portions of this vein are strong, and dislocate the strata very much, but in opposite directions. Like some of the Nenthead cross veins, by hading to each other, they must become one vein, at no very great depth below the surface.

Rodderup Fell cross vein has not been found on the south-west side of the Great Sulphur vein. This vein is moderately strong, and throws up the west side about 12 feet.

One or two weak cross veins intersect Cross Fell vein near the Smelt Mill. They are probably identical with the Nether Hearth cross vein, which may divide into two portions in its direction northward.

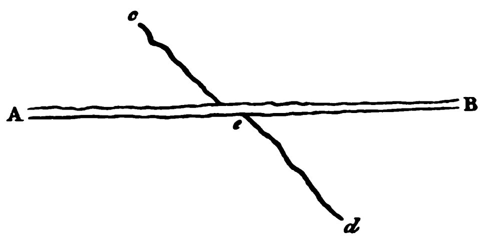
Such is a brief description of the principal cross veins which traverse the Alston Moor mining district. Two questions naturally arise—Is their formation due to the same laws of causation as the east and west veins; and what is the date of their formation in relation to the latter kind of veins?

Werner was the first to point out the importance of intersections in determining the relative period of the formation of veins. He laid down the general law, "that every vein which *intersects* another, is *newer* than the one traversed, and is of *later formation* than those which *it traverses*; of course, the *oldest vein is traversed* by all those that are of a *posterior formation*, and the *newer* veins always cross those that are *older*."* This appears

* 'New Theory of the Formation of Veins,' chap. iii., sec. 31.

unexceptionable so far as it goes. In its application to any particular case, it is necessary, however, to determine the intersected and intersecting veins. The Saxon Professor takes it for granted that this can easily be done. My impression is that to make such observations correctly, is in the majority of cases a very difficult undertaking, requiring not only careful examination in the mine, but also all the aid that can be derived from a profound analysis of the facts.

For instance, let us suppose a district like Alston Moor traversed by a strong cross vein A B, which dislocates the



strata some 10 or 20 fathoms. After some indefinite period, let us suppose another weaker vein, *c d*, formed. Now; if the strong cross vein is filled with douk, as is almost invariably the case in the upper beds, it is evident that a fissure formed in such soft clayey matter must almost immediately close, leaving no room for the deposition of various kinds of sparry mineral or metallic substances, which may afterwards be deposited in the vein, *c d*. Let us suppose further that mining operations are extending from *c* to *e*, or from *d* to *e*; when *e*, the point of intersection, is reached, the sparry minerals and metallic substances are abruptly cut off, and it may be, all trace of the vein is lost: especially if the posterior formed vein occurs a few feet or fathoms out of its direct line of bearing. In such instances, an ordinary observer would consider the vein *c d*

as the intersected vein, and the older formed vein the intersecting one; and he would be justified in doing so from Werner's definition of the phenomena presented at the point of intersection, namely: "When two veins cross, one of them, without suffering any derangement or interruption, traverses the other; this last is interrupted and cut across, through its whole thickness, by the former. The first of these is said to traverse the other, and the latter to be traversed by the former."*

For this supposititious case, real instances of bad observation might be substituted. Mr. Forster observes "that, in *Alston Moor* the veins, bearing north and south, called *cross veins*, generally traverse those that are termed *right running veins*, which pursue a point nearly east and west. If Werner's doctrines are correct, we may, therefore, infer that *cross veins* are of a more recent formation.† With this conclusion Professor Phillips seems to concur. Speaking of the connexion between the metalliferous veins, and the great lines of disturbance, as the Penine fault, &c.; he observes, that the numerous faults of an ordinary character which cross the country in all directions between those great lines of convulsion, seem evidently related to and dependent upon them;—a remark which receives corroboration from many parallel inquiries. Amongst these faults it is possible, perhaps, to distinguish two periods of disturbance,—*the older one* marked by a direction nearly *east and west*, which is that of most of the metalliferous veins, the other by a direction from north to south, which is that of several whin dykes, and some few lead veins. Perhaps these different directions may have taken their rise from

* 'New Theory of the Formation of Veins,' chap. iii., sec. 31.
† 'Treatise on a Section of the Strata,' p. 209.

the two directions of the axis of convulsion which bound the district.*

Excepting the few instances given by Mr. Forster, which could not be easily explained by Werner's doctrine of intersections, I am not aware that these opinions have ever been very seriously questioned. By the miners in Alston Moor, the cross veins are always considered as later formed, and on that account *produced* certain effects, well known to them, upon the prior formed east and west veins.

If it is granted that the east and west veins were formed before the cross veins—that Crag Green sun vein, for instance, was formed before Garrigill Burn cross vein—then, from the facts respecting the former vein, it follows; that, this moderately wide east and west vein, dislocating the strata a number of feet, terminated at one point, without leaving the least vestige of its existence on the strata in its general line of bearing; and also that, at some future indefinite period, Garrigill Burn cross vein was formed, and traversed the district in such a direction, that it coincided exactly with the point where the east an l west vein terminated. In this case every individual, who understands the subject, must admit a *reductio ad impossibile*—must admit that the two conclusions are incompatible with each other.

Crag Green sun vein forms part of Fletcheras vein, and splits from it, on the west side of the Tyne river. Now, Fletcheras vein is found on each side of Garrigill Burn cross vein; it also passes through Black Ashgill cross vein; and at the points of these crossings, I have no doubt, presents all the appearance of an intersected vein; but at Carrs vein both it and most of the other Nentsberry Green veins terminate in the same manner as Crag Green sun vein. Thus supplying an instance of a vein split

* 'Manual of Geology,' p. 571.

up into two parts (in connection with several others), both terminating when possessing their full magnitude and throw precisely at points where two cross veins were afterwards to be formed!

In the same manner, it is probable that several of the Hudgill Burn veins terminate at Black Ashgill cross vein. These veins have not been worked at the point of their intersection with this cross vein: the direct proof that such is the case is therefore wanting; but as there are no east and west veins found traversing the district in their line of bearing, the indirect proof is almost equally conclusive.

The Nenthead Fields veins also terminate abruptly at Carrs vein.

Several of the veins composing a part of the Browngill vein, either terminate in the same manner at some of the cross veins, or undergo some considerable modification both in width and throw. Hangingshaw vein and Middle Cleugh vein both terminate at Carrs vein. The Whitewood portion of Rampgill vein terminates at one of the Coal Cleugh cross veins, and Scaleburn or Low Coal Cleugh vein terminates at the west portion of Whetstone Mea cross vein. Middle Cleugh vein is of considerable width and throw, but on the east side of its intersection with Carrs vein, it exists as a mere string, with only a few inches throw. Middle Cleugh second sun vein, in its direction eastward from the point of intersection with Carrs vein, gradually changes its throw and hade; but, at the point of its intersection with Handsome Mea great cross vein, these are reversed. On the east side of this cross vein, it throws up the south side about 11 feet, and on the west side, it throws up the north side 11 feet. On account of the vein hading in opposite directions there is an apparent shift of 180 feet or more in the Firestone and Slate Sills, while at the point of intersection in the Great Limestone the shift amounts only to a few feet. (See Plate VIII.) It will be evident,

to every one who clearly comprehends these facts, that such phenomena could not be produced by any longitudinal shifting of the strata, at the time of the formation of the cross veins, on the supposition that the latter were formed after the east and west veins.

It is unnecessary to pursue the subject further. Notwithstanding in all the instances we have adduced, the cross veins are *apparently* the intersecting and the east and west veins the intersected ones,—the facts pointed out are sufficient to establish the following proposition, namely, *the cross veins in the mining district of Alston Moor were formed either anterior to, or contemporaneously with, the veins which traverse the district in an east and west direction.*

The question now arises—Are there any phenomena, or class of facts known, sufficient to establish the prior existence of the cross veins?

We have shown that the existence, magnitude, and direction of the east and west veins are dependent upon a certain line or axis of unequal elevation of the enclosing rocks. Like all other operations of Nature upon inorganic matter, the production of mineral veins is doubtlessly due to causes whose effects are uniform. If the two classes of veins were produced contemporaneously we might reasonably expect that their existence would be connected in causation with the same phenomena —would be dependent upon the same axis of unequal elevation.

It will be observed upon the map that the cross veins pass through the axis of elevation situated at the head of the Tyne and Nent rivers, without any apparent modifications of their bearings and throws as they approach it. In this respect they differ from the east and west veins. It is true that in the Kilhope district the Coal Cleugh East cross vein decreases in magnitude while that of the West cross vein is considerably increased;

the strata being elevated much higher on the west than on the east side of these cross veins. Changes, however, similar to those take place, in connexion with some of the cross veins, in the Nenthead district, without passing through an axis of elevation. But as there is a rise of the strata south-west, or in the direction of the axis from Long Cleugh head to Burnhope Seat, at the first glance it seems probable, that the existence of the cross veins may be connected with the rise of the beds in this direction, and consequently connected in causation with the formation of the east and west veins.

Plate VII. Section No. 1 is made on the line of a portion of this axis extending from Patterdale vein to Burnhope Seat (between A and B upon the general map). It will be perceived that all the strongest veins throw up the west cheek, or in the direction of the acclivity of the strata on the line of the axis. The inclination of the beds between the different veins is, however, chiefly to the west; thus tending to neutralize the effect of their throws. From Black Ashgill east cross vein to Burnhope Seat there are no veins of any kind to disturb the uniform inclination of the strata. Now, if in that portion traversed by strong cross veins, there is a greater amount of effect produced towards elevating the strata than in the undisturbed portion, we might be justified in concluding, that, at the time of the elevation of the axis, the strata were subjected to a greater amount of tension in the former than in the latter case. This, however, has not been the case; for, when the line of inclination in the south-west portion, is continued through the disturbed portion to the east side of Patterdale vein, it is found to coincide with the thrown-down cheek of this vein. Or, in other words, if these veins had no existence, the horizontal position of the strata on the east side of Patterdale vein would not have been different from what it is at present.

Here, then, where there are no east and west veins to complicate the inquiry, there is no evidence to establish a connexion in causation between the formation of cross veins and this axis of elevation which is intersected by them. Nor, in consequence, any proof of the contemporaneous formation of the two classes of veins.

We have already stated that the east and west veins traverse the district on the level line of the beds. Variations from this law occur when the veins are dwindling to nothing, or in some limited portions which are due to some local conditions. Section No. 2 is drawn in the direction of Long Cleugh vein, on the east side of Carrs vein. This section exhibits the throws of the cross veins, &c., and their effect upon the strata does not appear to differ much from No. 1. It will be observed that the beds are less elevated at the east than at the west end of the section, and in connexion with this circumstance Long Cleugh vein gradually becomes of less magnitude, if it does not altogether cease to exist on the west side of the point where it should intersect Middle Cleugh second sun vein. A section drawn on the line of the latter vein exhibits the beds on the east side of Patterdale vein and the west side of Black Ashgill vein lying in the same horizontal plane.

Section No. 3 is drawn on the line of Rampgill vein. When compared with the two last sections, it will be perceived, that the throws of these veins and the inclination of the strata are considerably modified. The strata are displaced by Black Ashgill vein not less than 60 feet, and, between this vein and Carrs vein, no other vein exists to displace the strata in a contrary direction, as in sections Nos. 1 and 2; since Cowhill and Cowslitts are both weak veins and produce scarcely any effect upon the beds. The throws of the veins on the east side of Carrs are diminished, only one or two displacing the whole thickness of

the Great Limestone. Between Black Ashgill vein and Rampgill cross vein the strata are lying at various degrees of inclination and in opposite directions; but on the opposite sides of these veins they are found nearly in the same plane of elevation.

Section No. 4 is drawn on the line of Guddamgill vein. On the east side of the Nent river the cross veins shown on No. 3 have combined with each other in such a manner as to form two strong veins, namely Carrs and Guddamgill Burn veins. The former throws up the west side 240 feet, the latter the east side about 46 feet. Black Ashgill cross vein is split into three portions, and the throw of this vein is considerably diminished; but, as in the last section, on the opposite sides of all the cross veins, the strata are found in the same plane of elevation.

Section No. 5 is drawn on the line of the Brownley Hill and Grassfield veins, and also shows the throws of the strong cross veins as well as the inclination of the strata from them. At this point Guddamgill Burn vein is reduced to a mere string, and is not shown upon the section. Another, called Wellgill cross vein, has formed on the west side, which displaces the strata to the same amount. The throw of Carrs vein is nearly the same as in Section No. 4. On the west side of the west portion of Black Ashgill cross vein, and on the east side of Guddamgill Burn cross veins, the beds are found placed in an equal position of elevation.

Section No. 6 is drawn on the line of Hagg's or Fletcheras vein. It varies very little from the section on the line of Brownley Hill vein.

Section No. 7 is drawn on the line C D upon the map. It does not correspond with the direction of any east and west vein, but, as might be expected from the angle it makes with the Holyfield and High Raise veins, the beds are found lower on the east than on the west side of the cross veins. It will be

perceived that Carrs vein is ramified or split into two portions. The throw of the west portion is much less than that of the other. It is called Blaygill cross vein, and in its direction northward gradually increases in magnitude and throw.

Few mining works have been made in these cross veins further north. In consequence, cross sections could only be made somewhat indirectly, after long and careful investigations, by levelling, &c., upon the surface. Those given are, however, sufficient to render doubtful the hypothesis of the formation of the cross veins being connected in causation with the formation of the east and west axis of elevation.

That the strata were subjected to much tension, before they were fractured and dislocated so much as is represented upon this series of cross sections, is a conclusion that hardly admits of question. Now, in Alston Moor at least, all evidence of their being connected with an axis of elevation is wanting; it does not therefore appear an improbable hypothesis, *that, at the time of the formation of the east and west veins, the axes of elevation connected with the cross veins were obliterated, and the dip of the strata changed to nearly at right angles.*

If we adopt this hypothesis, we may infer, that at the time of the formation of the east and west veins, several cross veins might come into existence, and combine with the prior-formed ones, in such a manner, that it is now no easy matter to distinguish the one set from the other. As most of the cross veins hade to each other so rapidly in a downward direction, they must become one vein at no great depth below the surface; it is not unlikely, but that the formation of some of them is connected with subsequent movements in the strata (facilitated by the prior-formed cross veins as lines of weakness), the effect of which was, in a great measure, to level former axes of elevation; thus rendering it very difficult, if not impossible, to de-

termine what was the relative position and inclination of the strata prior to the formation of the east and west veins. From the uniform direction of Carrs vein through many miles of country, not only in Alston Moor but also in Weardale, I am led to infer, that the axes of elevation connected with these cross veins must have traversed the mining districts in a parallel direction: and it also seems probable to me, that when the strata were moved by forces of elevation, in an east and west direction, the effect in the first instance might be to raise the depressed portions lying between such axes or ridges into an equal position, and this more particularly near the line of greatest intensity of force, and likewise form at the same time the east portions of the cross veins; and that afterwards the beds were again wrenched into unequal positions of elevation, and the formation of the east and west veins effected.

From facts of a more particular kind, but which are difficult to describe clearly, I am led to conclude that Carrs vein, at least, must have been in existence prior to the formation of the east and west veins. Some of the latter, which terminate at Carrs vein, for some distance on the west side, throw up the north cheek although the acclivity of the beds is in a contrary direction. Before the strata gave way, it would appear a considerable amount of force was pent up, sufficient to prolong some of the east and west fissures to this cross vein; or, beyond the point necessary for the rocks to be fractured and displaced, to allow of portions being raised to higher positions, and in different planes of inclination.

We are now in a position to affirm, that the cross veins, as well as the east and west veins, were in existence soon after the close of the Coal-Measure period, and before the formation of the lower Permian rocks. The Magnesian Limestone rests unconformably upon the former, and the Ninety-fathoms dyke passes

underneath the latter without dislocating its beds. It is owing to the movements effected at the time of the formation of the metalliferous veins of Alston Moor and the adjacent districts, that the rocks were subjected to denudatory forces, from which they had been exempted ever since the commencement of the Old Red Sandstone formation.

CHAPTER VI.

OF THE QUARTER POINT VEINS OF ALSTON MOOR.

IN the upper part of the district, this class of veins is generally of very small magnitude, their throws not exceeding a few inches. The strongest in the Nenthead mines is Rampgill second sun vein, which dislocates the strata about six feet. For about 180 fathoms Rampgill vein traverses the district in the direction of this quarter point vein. It would appear, therefore, that it had formed a line of least resistance, and may have been in existence at the time of the formation of the east and west veins.

In the lower part of the district, veins of this class appear to be much stronger. There is one in the Rodderup Fell mine, bearing in a north-east or south-west direction, which throws the north-west side up not less than 40 feet. This vein is parallel with several veins or dykes of still greater magnitude, that are found in the old collieries situated at Gilderdale head.

We have stated above, that one of these quarter point veins has formed a line of least resistance for Rampgill vein, and that for some considerable distance. In connexion with the east and west veins, a few instances of this kind occur in other parts of the district. I am not aware, however, of any cross

veins being diverted from their line of bearing in a similar manner; and in consequence I am led to suppose, that the quarter point veins were formed posterior to the cross veins, and either contemporaneously with, or anterior to, those of the east and west veins. With respect to this alternative, it may be observed, that the relation of veins to each other with reference to their period of formation can only be safely determined by careful observations of their connexion with the inclination and position of the strata. It is only in the upper part of this district that I have had opportunities of studying this connexion where, as just observed, the veins are comparatively weak. In consequence of which I have not been able to arrive at a more definite conclusion.

Having now brought the inquiry to a close, we shall state, in a few aphorisms, the conclusions arrived at.

I. The strata were originally thrown down in nearly a horizontal position. This could only be effected by an equal subsidence of sea-bottom throughout wide areas, and that during the whole period occupied in the deposition of the Old Red Sandstone, Mountain Limestone, and Coal-Measures.

II. That at the close of this period, and before the Permian rocks were deposited, this vast thickness of rocks was thrown out of its horizontal position by forces of subsidence or elevation, probably the latter, and the cross veins formed, these being simply fractures parallel to lines of greatest effect produced.

III. Afterwards the great axis of elevation, which commences at Cross Fell and extends eastward, was formed, and with it a series of east and west veins, the formation and direction of which evidently depend upon the tension the strata were subjected to by unequal elevation and the irregular bendings of this line of greatest intensity of force, as indicated by its effects.

When this took place the Coal-Measures had not been removed from the Millstone Grit.

IV. The denudation of the Coal-Measures now took place, and also the formation of the Permian rocks, the action of the denudatory forces being regulated by the lines of greatest elevation of the rocks, the Coal-Measures being entirely swept from off broad areas of country.

During the period in which this immense mass of matter was removed the whole series of sedimentary strata comprised between the Permian and the Pleiocene, inclusively, were deposited in the bottoms of the surrounding seas. At its termination the tops of the Penine mountains, and those extending eastward from Cross Fell to beyond Kilhope Law, were islands dotting the surface of the ocean, their summits being at least 1800 feet lower than at present. From these ice-bound islands masses of ice were floated off during the summer to be dashed and broken on tempestuous coasts. What a contrast to the mild atmospheres and splendid vegetation of the Carboniferous period! Numerous races of animals had flourished and passed away, and the majority of species now inhabiting the earth had come into existence.

At the termination of the Glacial period the whole of the district between the Penine fault and the German Ocean was slowly elevated, in a manner analogous to the slow and equal subsidences throughout wide areas, which took place when the strata were deposited, the effect of the elevatory force being inversely proportional to the distance from the Penine fault. My convictions are, that the axis of elevation and associated mineral veins were scarcely if at all affected by this last great upward movement. There is some reason to conclude that the Great Sulphur vein is later formed than the east and west veins. Numbers of the latter, even of a weak character, are found on

each side of the former; on account of the acute angle made by the intersections of these veins this could hardly have occurred had they all been formed contemporaneously; yet at the close of the Glacial period the Great Sulphur vein contained the same quartz minerals it does at the present time. Again, had this vein been reopened and further dislocations been effected after this epoch, lines of precipitous cliffs must have been formed at several places where hard rocks are lying near the surface. Such is not the case; the surface, with the exception of a few conical hills, is smoothed off without being modified in the least degree by the existence of this powerful vein in the rocks below. Nor is it at all probable, that a line of cliffs on the summits of the mountains could be worn and eroded by pluvial and hyemal agencies, since the ribs of quartz contained in this vein and the hard sandstones composing its walls or sides are nearly as indestructible as the granite boulders, which must have been exposed to the action of these agents on the opposite side of the mountain.

V. If, since the glacial epoch, the district of Alston Moor has been raised some 1800 feet, it is evident that this must have been effected by a more wide-spread or deep-seated force than that which produced the axes of elevation then in existence. It appears also, that during this upward movement the dislocations occurred chiefly, if not entirely, at the *great lines of fault* as lines of least resistance; wide tracts of country being uniformly raised, the axes of elevation which traversed it were not modified, nor further dislocations effected on the lines of the correlated mineral veins.

It will be observed, that the antecedent, or cause of all these changes and resulting phenomena, is simply the subsidence and elevation of a portion of the earth's crust. But what is the cause of this oscillation, and what are the laws of its action?

To these questions science has as yet furnished no satisfactory reply. Attempts have been made to establish a relation in time between parallel mountain chains or axes of elevation. But the grouping of effects based on this relationship throws no light on the laws of causation, and until this is determined by induction, it seems probable that the subject will continue to be shrouded in much obscurity.* Whatever law regulates the action of these forces, we may rest assured that, like all the rest in Nature, it must be uniform and eternal, the mandate of a Supreme Being with *whom there is neither variableness nor shadow of turning.* Or, as it has been well expressed by a profound thinker, "The searching eye of man, whether he regards his own inward being or the creation surrounding and encompassing him, is always led to the Eternal Source of all things. In all inquiry the ultimate aim is to discover that which really exists, and to contemplate it in its pure light, apart from all that deceives the careless observer by only a seeming existence. The philosopher will then comprehend what, amidst ceaseless change, is the Constant, the Uncreated, which is hidden behind unnumbered creations; the bond of union which causes things not to fall apart in spite of their manifold divisions and separations. He must soon acknowledge that the independent can only be the constant, and the constant the independent, and that true unity is inseparable from either of these. And thus it is in the nature of thought that it finds no quiet resting-place, no pause, except in the Invariable, Eternal, Uncaused, All-causing, All-comprehensive Omniscience."†

* See Johnstone's 'Physical Atlas.'

† Oersted's 'Soul in Nature,' p. 136.

BOOK II.

THE LAWS WHICH REGULATE METALLIFEROUS DEPOSITS ILLUSTRATED BY AN EXAMINATION OF THE GEOLOGICAL STRUCTURE, AND OF THE LEAD VEINS OR LODES OF ALSTON MOOR.

"Whosoever understandeth the fructifying quality of water will quickly apprehend the congruity of that invention which made the cornucopia to be filled with flowers by the Naiades or Water Nymphs."—*Sir Thomas Browne's Miscellanies.*

CHAPTER I.

OF THE MODE OF PROSECUTING THE INQUIRY.

We have shown that the district of Alston Moor is diversified by hill and dale, formed by the erosion of vast quantities of stratified rocks; that the eastern part of the district is traversed by powerful north and south veins, locally termed cross veins, which dislocate the rocks, often, to a very considerable extent; and that these veins are intersected with two other classes of veins, respectively termed weak quarter point and east and west veins. It is from the east and west veins that the greatest quantities of lead ore have been produced for many generations. We have also shown that in connexion with these veins the stratified beds are lying at various angles of inclination.

It is now necessary to observe, that the lead ore has not been deposited uniformly in any of the veins, but, on the contrary, that large portions of the richest veins contained very little, and that those portions which have been worked or cut out for the ore they originally contained varied very much in their productive character, probably in each extreme not less than 100 to 1 bing (8 cwt.) per fathom. The *minimum* quantity per fathom that will repay the cost of mining is necessarily dependent upon the softness of the accompanying vein-mineral, and also of the enclosing rocks.

We have also shown that these veins have not always been in existence, that they are not contemporaneous with the enclosing rocks; but that when first formed they were only simple fissures containing no vein-minerals. The accumulation of lead ore in certain portions of the vein must be a resultant from certain antecedents regulating such deposition. If the uniformity of Nature's laws, whether chemical or mechanical, be admitted, it follows that *a certain* class of antecedents or causes must have invariably preceded the deposition of lead ore in all cases. To ascertain these is an inquiry the most important to practical mining.

Two theories have been proposed to assign the source from which the ore has been derived or its elements have been supplied; the one supposes it to be a segregation from the enclosing rocks, the other a sublimation from great depths and connected with volcanic influences.

It is necessary to observe, that the laws which have regulated the distribution of the ore in the veins may be of a different character from those connected with its origination; the former may be mechanical, the latter, if the metals are substances compounded from certain elements unknown in a separate state, must be chemical. If, however, they are simple substances, which have risen to the surface as gaseous emanations from the interior of the earth, then the distribution or accumulation of the ore into certain portions of the veins may have taken place after its deposition sparsely throughout the whole extent of the fractures in the rocks. If they are derived from rocks, in which their existence cannot be detected then the compounding and localization of the ore may have been contemporaneously effected.

If metals are compound substances, as some of the most able and ingenious chemists have supposed, then a knowledge of the

process or processes by which Nature has manufactured such large quantities of valuable metals would be exceedingly interesting, even in a scientific point of view alone, though it seems improbable that its use would be altogether restricted to chemical experiments or to abstract speculations, and that it should not in some form or other ultimately prove practically beneficial to the interests of man; but were we in possession of this knowledge, and had the requisite skill to produce such substances so essential to civilized life, it is questionable whether we could do so economically; it is not improbable, but that we should be under the necessity of searching for them as at present by mining operations. Should this be the case, a knowledge of the laws, which have regulated the distribution of the ores in the veins, would even prove more valuable to the practical wants of man than the knowledge of the laws of their combination from *elements*, whether these are derived by sublimation from beneath or segregation from the rocks.

The experiments of Becquerel and others have shown that metals in solution may be crystallized and combined with other substances by electro-chemical agency, forming minerals exactly similar to those found in Nature. Interesting as those experiments are, in a scientific point of view, they render no assistance to the practical miner in guiding him to the deposits of metallic ores so irregularly distributed in the veins. Their experiments relate more to crystallography and mineralogy than to practical mining; and it should be borne in mind that crystals of various kinds are found where none of the ores of the useful metals exist. Nor do these experiments throw any light on the source whence the metals have been derived. They only show that electro-chemical forces *may* have been feebly exerted throughout the long periods of time necessary to the accumulation of the ores in certain localities. The practical miner has

still to depend upon expensive explorations,—frequently long and tedious,—before he meets with the valuable ores, the only reward for all his toil and anxiety; and even after making the most extensive explorations, he is often doomed to disappointment and the loss of all the capital expended.

No kind of mineral contained in the veins of Alston Moor varies so much in quantity, in different parts of the same vein, and in the same stratum, as lead ore. It is found plentifully deposited with quartz, carbonates and sulphides of lime and iron, fluorspar, barytes, oxides of iron, Black Jack, &c., and it is frequently absent in the same stratum, when the veins contain large quantities of some one or other of these minerals. Hence, its deposition is not dependent upon the presence or absence of any one of these minerals; and whatever may have caused the deposition of the latter, it is evident that it has not interfered to prevent the operation of those causes which regulated the deposition of lead ore. If the variation in amount of lead ore, in the same vein, and in the same stratum or kind of rock, is greater than that of any other mineral, the law of such variation is more likely to be ascertainable.

If, however, ores in veins are due to sublimations from beneath, and are found plentifully *only* in those places where the exhalations effected a free passage upwards, the causes or conditions might be of a deep-seated character far removed from observation. Then the apparent discordance of the phenomena, observed to be connected with deposits of ore, in the veins, would not be at all likely to be cleared up, by even the most careful generalization and elimination of particulars, nor, consequently, the risk of mining speculation at all lessened, by the most elaborate statements of facts. Deep-seated causes are the least likely to be ascertained: indeed, it does not seem at all improbable but that even all trace of them might vanish as soon

as the deposits were made, and this more especially, if connected with melted matter in a state of volcanic activity. But even in such cases, where we would fail to perceive orderly arrangement, the laws of deposition would be uniform; although in seeking for them we should wander in the dark mazes of experience, out of which the most orderly methods of investigation would fail to lead us to the open daylight of axiomatic truth.*

In Alston Moor, the veins have been the most productive in situations furthest removed from Plutonic action; the richest deposits having been effected in the upper part of the Mountain Limestone, where no igneous rocks are found, either in the form of dykes, or sheets intermingled horizontally with the stratified rocks. The lower part of the strata, in this district, comprehends a stratum of Basaltic Greenstone, and also a Basaltic dyke, but the veins generally have contained very little lead ore when these rocks form their sides, or walls. Doukeburn east and west vein, has been proved to contain scarcely any ore, for a considerable distance, on each side of the Basaltic dyke. So far as this district is concerned, there is nothing to support the theory that lead is due to exhalations from beneath, or to matter injected in a fluid state among the consolidated sedimentary rocks.

The nodules of carbonate of iron, so often found arranged in layers in beds of shale, have generally undergone some degree of contraction in the interior; after the exterior has been consolidated to a degree sufficient to limit the shrinking of the central part of the mass. Into these cracks, sulphides of lead, zinc, and iron, copper pyrites, and certain other minerals of a different class, have not unfrequently been introduced. In such

* Bacon's 'Novum Org.' I., 82.

cases it seems exceedingly improbable that those substances could be derived from exhalations from beneath. There can be little doubt that their component parts have come by infiltration from without, through their exterior pores, and through those and the laminæ of the surrounding argillaceous shales. It also is evident that these bodies or their component parts were in a soluble state when they entered the cavities formed by the cracks of the nodules.*

Such infiltrations are not limited to the nodules of argillaceous shales, but have often been introduced into the cavities left by the decomposition of mollusc-shells, in various kinds of rocks. At St. Agnes, Cornwall, crystals of Felspar have been removed from Elvan and replaced by peroxide of tin. Instances of this kind are of a deeply important character, and are almost conclusive that metals or the elements of metals are diffused, perhaps in varying proportions, throughout the whole mass of all kinds of rocks. They indicate, probably, that the existence of metals in veins is the result of combinations and changes, which cannot be always, if indeed ever *directly* connected with volcanic influences; and although the quantities of metal infiltrated are infinitesimally small, when compared with the deposits in veins, they may be regarded as *instantiæ crucis*, indicating at least the direction which the inquiry ought to take. Lord Bacon observes, "that mean and small things discover great, better than great can discover small, and therefore Aristotle noteth well that the nature of everything is best seen in its smallest portions."† The same sentiment is also more forcibly expressed by the poet:—

> "Duntaxat rerum magnarium parva potest res
> Exemplare dare et vestigia notitiai."—*Lucr.*

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* Sir H. T. De la Beche's 'Geological Observer,' p. 764.
† 'De Augmentis,' Lib. II. 2.

Assuming therefore, as the more probable view of the case, that the deposition of lead ore in the veins of Alston Moor is due to segregation from, or decomposition of the rocks, which form the walls of the veins where such deposits are found; then, the regulating causes must be sought for in the phenomena connected with the rich portions of the veins and enclosing rocks, and equally so in the phenomena connected with the unproductive portions. The former should be carefully studied, in order to discover if possible the functions they are adapted to perform, or the natural forces they would call into action as effecting the deposition of lead ore; the latter, in order to discover their inadaptation to produce the same results.

Viewing the subject in this light, it is evident that the action of the regulating causes must have varied in intensity, proportional to the effect produced, providing there was no modification of such effects by the interference of other causes; for instance, such modification would result from a variation in the amount of space left open, when the fracture was produced. The width or the original open space in veins is generally proportional to the amount of throw they possess; but this is not invariably the case; the same generally very wide vein is sometimes straight in hard rock even where no diminution of its throw has taken place. Occasionally, the wide open spaces in a vein have been completely filled with shale, shortly after the formation of the fissure, thus preventing entirely the deposition of metallic substances.

closing rock, or where it constitutes the sides or walls of the vein. And probably such conditions are found to be the most clearly connected with a portion of Rampgill vein, extending westward from the boundary between the Coal Cleugh and Nenthead mining districts to the Nent river; for through the whole extent of this ground it is uniformly wide and generally well filled with vein minerals. The very rich deposits of lead ore are, however, in a great measure limited to the east portion, which is included in a length of 300 fathoms. From this portion vast quantities have been produced, in all, probably, not less than 300,000 bings.* The remaining portion has not contained much ore: indeed, so far as deposits in the Great Limestone are concerned, it may be considered as an unproductive or barren vein. If the inquiry is restricted to the vein in the Great Limestone, it is probably reduced to the simplest form the subject will admit of.

We shall endeavour to point out the dissimilarity of the conditions connected with the rich portion of this vein and the enclosing rock, and those connected with the poor or unproductive portion. The sketch Plate IX., may be called a plano-section of Rampgill vein. The ground on the south side of the section is intended to represent the Great Limestone, as it would appear if denuded of the superincumbent strata, which at the boundary between Northumberland and Durham comprise a series of beds not less than 600 feet thick. The drawing combines a section on the line of Rampgill vein, extending from the Nent river to Swinhope-head, clearly denoting the inclination and various dislocations of the strata, with a plan of the ground to the south, which as clearly shows the boundaries or Heaven's-water divisions, as well as the supposed position of the anticlinal axis on the

* A bing is 8 cwt.

Durham side of the boundary. It also shows the direction of the quarter point and cross veins, which form intersections with Rampgill vein; the throws of the latter being denoted upon the section. It will be observed, from this plano-section, that the Great Limestone stratum on the west side of Carrs vein (No. 1) is almost entirely wasted away by the abrasive forces connected with the formation of the valley of the Nent. It is necessary therefore to eliminate this portion from the inquiry.

Commencing at Carrs vein, the first circumstance to be observed is that this cross vein dislocates the strata not less than 84 feet, the east cheek being thrown down. Another dislocation takes place a short distance further east by Small Cleugh cross vein (No. 2); the strata are thrown up about 48 feet or more on the east side. These two cross veins combine a little north of their intersection with Rampgill vein. On the east side of Small Cleugh vein the strata dip to the east, till they reach Low Fairhill cross vein (No. 3); they are then thrown up a few feet: their position, however, is almost immediately changed by the throw of High Fairhill cross vein (No. 4), which throws the strata down on the east side not less than 24 feet. The strata continue to dip rapidly to the west portion of Handsome Mea great cross vein (No. 5), where they are dislocated some 24 feet, the east side being thrown down. The East portion (No. 7) throws up the strata some 73 feet, or brings the Great Limestone nearly into the position it occupies on the west side of High Fairhill cross vein. From the east portion of Handsome Mea cross vein the strata continue to dip in the direction of Rampgill vein until Patterdale vein is reached, where they are again thrown down very considerably. From this point the beds commence to rise and continue to do so without interruption to Rampgill cross vein, where they are thrown up only four feet; from this cross vein they continue to rise to

the summit of the hill which divides the vales of the Nent and the Allen.

Taking a general view of these conditions, in relation to the inclination of the beds, it is observable, that in the rich portion of the vein they incline in a direction from the east to the west, or towards the valley, which the vein crosses at nearly right angles. In the unproductive ground, the inclination is towards the summit of the hill, or in a contrary direction. It may also be observed that no lead ore of any importance has been deposited below the dotted line *a b*; it is not until the bottom of the stratum has risen from Patterdale vein to the position represented by this line, that the vein is filled with lead ore throughout its whole thickness.

In the productive portion of the vein, the largest quantities of lead ore are invariably found where it is intersected with quarter point veins, which are well shown upon the plano-section; at such points of intersection, the effect towards the deposition of lead ore is intensified to a high degree, beyond the ordinary large quantity found in this productive vein. We have already observed, that these quarter point veins are very straight, and contain no vein mineral of importance; indeed they have a greater correspondence to simple fissures than mineral veins. The strata rise gently in their direction south-eastward to the anticlinal axis, which is represented upon the plano-section with uncoloured space. It is evident that all the water which might descend into these fissures would flow in the open spaces contained between hard strata towards Rampgill vein; and that the open spaces in this vein would continue the circulation westward to the point of its intersection with Patterdale vein. In this respect Rampgill vein would naturally form a kind of main drain or channel, into which all these small veins would discharge the whole of the water or fluids circulating in them.

The dip of the strata, as we have seen, being to the west, the circulation of the fluids must have been in that direction. The unproductive portion is also much intersected by cross veins and north and south strings or leads connected with them. But it should be especially observed, that these veins seldom contain any lead ore or other kinds of vein-mineral in the strata above the Great Limestone. They are usually filled with a pasty clay called by the miners douk. This clayey matter is evidently composed of argillaceous shale either decomposed by percolating fluids or pounded by the friction occasioned by the formation of the vein. And a dyke of pounded clay pressed firmly in the interior of the vein is very unfavourable to a *free* circulation of water, be the inclination of the beds ever so favourable, although it may slowly percolate it. The beds rise southward in the direction of these veins, and in this respect do not differ from the very productive portion to the east.

It is probable that the east and west veins in the plate beds would be nearly filled with this pasty clay, or douk, at the time of their formation: we shall, however, shortly recur to this subject in connexion with the laws regulating the descent of water into the interior of the earth. It may be assumed for the present that such was the case: as a consequence, a circulation in Rampgill vein in such kind of rock would be prevented by this circumstance. Bearing this in mind, it will be found, upon a simple inspection of the section, that the greater portion of the strata below the Great Limestone in this locality is chiefly composed of shale, and from the elevated position of the thick plate bed below the Nattrass-gill Hazle on the west of Carrs vein, a free circulation of fluids or water in a longitudinal direction in Rampgill vein, was probably prevented in all the ground below the dotted line to the east side of Rampgill cross vein. In reference to that portion of the Great Limestone elevated above

the dotted line west from Patterdale vein, it may be observed that the dislocations of the strong cross veins would be a sufficient preventive to the circulation of water; the cheeks or sides of the vein composed of Great Limestone, being placed on opposite sides—against beds of plate, which are situated above or below this stratum; thus forming a constant interruption even in a *direction* by no means favourable to a free circulation.

We are now in a position to affirm, that the conditions connected with the very rich portion of Rampgill vein, in the Great Limestone, differ from those connected with the portion which has been very poor in this most *important particular;* that they would promote a *free* circulation of water or fluids in a longitudinal direction, *to* and likewise *in* the vein. The analogy of this circumstance with other great operations of nature towards the production of physical phenomena is very striking, and hardly needs be pointed out to the intelligent reader.* We have already observed that the variation in amount of lead ore in the same vein and in the same stratum is greater than that of any other mineral found in veins. The assumption is therefore warrantable, that such a variation is due in all cases to certainlaws regulating the circulation of fluids, the effect of such circulation being modified by various conditions. Under such circumstances, a certain analogy may be traced in the deposition and *crystallization of metallic* matter, with the circulation of sap in vegetable growths, and of fluids or blood in animal forms. And although the mechanical circulation of fluids in veins certainly differs

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* Humboldt observes that every being considered apart is impressed with a particular type, so, in like manner, we find the same distinctive impression in the arrangement of brute matter organized in rocks, and also in the distribution and mutual relations of plants and animals. The great problem of the physical description of the globe, is the determination of the form of these types, the laws of their relations with each other, and the *eternal ties which link the phenomena of life, and those of inanimate nature.*—'Travels in South America.'

very essentially from the *vis à tergo* which impels the sap upwards to the terminal point of every branch, or in animals, from the *vital force* concerned in assimilation and secretion, which probably not only changes the nature, but also produces the movement in a stream of which the flow is development;* still the circulation of fluids in veins may so far resemble that of sap in vegetables and blood in animals, as to promote certain chemical changes and combinations, to which not only the distribution, but also the origination of metallic substances in veins may be due.

* Dr. Whewell's 'History of Scientific Ideas,' vol. ii., p. 215.

CHAPTER III.

OF THE LAWS REGULATING THE DESCENT OF WATER BELOW THE SURFACE OF THE EARTH.

No extensive explorations can be made by mining in the interior of the Earth, without coming in contact with considerable quantities of water. In the mines of Alston Moor, the adits or levels are generally drains for the water to flow to the surface; and such adits are often planned with considerable care and skill, to accomplish this object the most effectively and economically.

Two theories have been proposed, to assign the source whence the water found in the interior of the earth is derived. One of them, now exploded, supposes that the veins are channels in which water has risen from great depths to the surface, at some former period; and that metallic ores have originally been held in solution by the water of these ascending springs, and deposited upon the sides of the veins. Many even suppose that the springs now issuing at the surface, not only in the valleys, but also near the summits of the mountains, are due to water ascending from the interior of the earth. So far, however, as a district like Alston Moor, formed of stratified rocks, is concerned, such a supposition is of a very unphilosophical character. For what is the force which must sustain and propel a column of water of several

thousand feet against gravity?* Nor does such a supposition appear the less strange when we bear in mind that the stratified rocks, through which it must ascend to elevated situations, are deeply cut into by valleys, as well as rendered porous by fissures traversing them in various directions. We may therefore exclude all consideration of ascending springs as a source of the water's flowing in the veins and fissures of stratified rocks; and so limit the investigation to the other theory which supposes that the water found among the rocks of this district descends from the surface.

The Sun is the great source from which the earth derives its heat. To the action of this heat the diffusion and suspension of water, in the form of vapour, in the atmosphere is due. This vapour is condensed and precipitated upon the earth as dew, rain, or snow. Hence by the influence of this heat a large quantity of water is kept in perpetual motion; for what is evaporated from the surface of the land or sea returns to it again in showers. This constant and compound circulation of the most universal solvent produces a series of never-ceasing changes upon inorganic matter, exposed to its action on the surface of the Earth, disintegrating the hardest substances, and, in some cases, carrying them unobserved by mankind generally, in springs of purest crystal, to some other locality, where, Proteus-like, they may assume other conditions of existence.

But its effects are not confined to things inanimate; it enters abundantly into the composition of animal and vegetable matter,

* No agency known of, excepting heat, could sustain and raise water to the surface against gravity. Occasionally it may have been forced up similarly to that of volcanoes ejecting melted matter; but the cause producing such effects would, in all probability, be spasmodic, and restricted to local conditions, and I think fails to account for the diffusion of those mineral substances, which have been attributed to such causes, so universally, and in the manner they are found in veins.

in each of which, while they are in a state of living organism, it is kept in a constant state of circulation, promoting important changes essential to their very existence. We cannot cast our eyes abroad without being forcibly reminded of the part which this substance plays in adorning the landscape with

"The pomp of groves, and garniture of fields."

In the dry countries of the East—the cradle of civilization—its effect towards causing the Earth to bring forth food for man and beast must have been forced on the observation of men in the very earliest times. Allusions are made in the ancient book of Job to such effects: "For there is hope of a tree, if it be cut down, that it will sprout again, and that the tender branch thereof will not cease. Though the root thereof wax old in the earth, and the stock thereof die in the ground, *yet through the scent of water it will bud and bring forth boughs like a plant.*" And similar allusions are frequently made in other parts of the sacred writings. Its effects have also formed a theme for poets, and a subject of the deepest thought to the philosopher. In a passage of great beauty, Lucretius, while proving that things cannot lapse into a state of non-existence, observes, that showers of rain which Father Ether precipitates into the lap of Mother Earth, though supposed by some to be lost, are not so, but that from them the shining fruits are produced, and the branches of the trees clothed with leafy green; the trees themselves are enlarged and burdened with produce; not only men but the race of beasts are nourished; joyful cities abound with youth; and the leafy woods resound in all directions with the songs of new-fledged birds; the weary herds, plump with browsing upon the rich pastures, repose their bodies, and the white milky liquor flows from their distended udders; their new-born offspring sports unrestrained with tottering limbs over the tender grass, their spirits exhilarated with the rich draughts of pure

milk.* Thales, the most ancient of the Grecian philosophers, maintained that everything arises or is originated out of water, and that into water all will again return or be resolved.

Nature peoples this wonderful fluid with innumerable beings too small for the unaided eye of man to perceive. Its vast reservoirs are also the abodes of life and enjoyment—the habitations of myriads of creatures from beings less than the tiniest shrimp, up to others whose gigantic proportions far exceed in bulk the largest terrestrial animals. Man economises the force which water produces in passing from a higher to a lower level; and as a motive power it grinds his corn, saws his timber, or crushes up the hardest stones to slime, and afterwards, by its action, the precious ore is separated from the worthless earthy matter with which it has been blended. It would be a hopeless task to enumerate all the useful effects produced by water in a fluid state. When it is converted into an elastic vapour a motive power is generated, which transcends all others in its adaptability to produce useful effects. It carries man and his merchandise across seas and continents with an untiring speed, which exceeds that of any other mode of locomotion, and almost that of the swiftest of the winged inhabitants of the air.

* —— "pereunt imbres, ubi eos pater æther
In gremium matris terraï præcipitavit:
At nitidæ surgunt fruges, ramique virescunt
Arboribus; crescunt ipsæ, fœtuque gravantur.
Hinc alitur porro nostrum genus atque ferarum:
Hinc lætas urbes pueris florere videmus,
Frondiferasque novis avibus canere undique silvas;
Hinc fessæ pecudes pingues per pabula læta
Corpora deponunt, et candens lacteus humor
Uberibus manat distentis; hinc nova proles
Artubus infirmis teneras lasciva per herbas
Ludit, lacte mero mentes percussa novellas.
Haud igitur penitus pereunt quæcumque videntur:
Quando alid ex alio reficit natura, nec ullam
Rem gigni patitur, nisi morte adjuta aliena."
Lucr. lib. i., 251—265.

The quantity of water which annually falls upon the hills, or rather elevated district, of Alston Moor, is probably not less than 55 or even 60 inches upon the highest parts of the country—a quantity nearly corresponding to the average amount of precipitation over the whole surface of the earth during one year.* A portion of this large amount of water is evaporated: the amount of evaporation, however, is probably much below the average of other districts, seeing that during a great portion of the year the sky is enveloped in clouds, collected by the attraction of the hills, and these clouds are only partially dispelled even by the heat of the summer months. The remaining portion must either flow upon, or sink beneath the surface. Now, of the quantity which falls upon the summit of the mountains a portion must flow to a lower level, and this quantity must gradually be augmented in some proportion to the distance from the water-shed of the mountain. Hence it is evident that the surface of a country must be more subjected to the influence of aqueous agency, when it is situated near the bottom of the valleys than upon or near to the summit of the hills.

Again, the quantity of water which sinks beneath the surface must bear some proportion to that which falls upon and flows over it, all other circumstances for promoting its descent being equal. Excluding for the present all consideration respecting veins and fissures in promoting the descent of water, we may observe that at the present time the water chiefly sinks into, or percolates, the joints of the harder rocks; open joints being rarely found in the beds of plate, the greater portion of it flows in the joints of such hard strata until it issues to the surface in the form of springs; and of the smaller quantity that per colates the beds of shale below, a portion circulates in the joints

* Johnstone's 'Physical Atlas.'

of the next hard stratum and issues to the surface. Hence the FIRST GENERAL LAW regulating the circulation of water in the interior of the Earth *is that, cæteris paribus, the quantity in circulation beneath the summit of the mountains must be in inverse proportion to the depth from the surface, and in direct proportion to the distance from the water-shed of the mountain.* We have already shown that joints gradually close and become fewer, and in many of the mines are not found to exist at even a moderate depth. This circumstance must therefore tend to lessen the quantity which would otherwise find a passage to great depths, were the strata at such depths equally broken with joints. The real amount circulating below the surface would probably be more truly represented by a series rapidly converging to zero. It is also evident that under those lateral ridges, extending from the summit of the mountain, towards the bottom of the valley, the circulation of water must be effected in a similar manner but in a lesser degree.

The quantity of water which descends is also affected by the declivity of the mountain sides. A great portion of the water precipitated upon the sides of steep mountains is gathered into rills in which—

> "Aslant the hollow channel rapid darts,
> And falling fast from gradual slope to slope,
> With wild infracted course, and lessened roar
> It gains a safer bed, and steals at last
> Along the mazes of the quiet vale."*

Under such circumstances the water quickly flows to the bottom of the valley, and in consequence there is less time for its percolating than when the sides of the mountains are gentle slopes covered with deep alluvial soil and herbage. Hence the SECOND LAW—*That the quantity of water sinking beneath the surface in*

* Thomson's 'Seasons.'

any locality must bear an inverse proportion to the steepness or inclination of the mountain sides. In accordance with this law, the quantity which sinks on the western side of Cross Fell, and into the steep sides of the mountains of the Cumbrian Lake district, must be very small compared with the quantity which sinks in the gentle slopes on the eastern side of Cross Fell or Penine range of mountains.

We have hitherto considered the conditions regulating the descent of water through strata lying horizontally, a case which seldom occurs in Nature. More generally the beds are lying at various angles of inclination. Now it is evident that water will circulate more freely in joints of strata having an inclination to the side of the hill, or towards the line of its out-cropping, than when the inclination is towards the interior of the mountain; a case resembling a drain or conduit with an inclination opposite to the direction in which the water is intended to flow. The former case will promote a freer circulation of water *near* the surface, the latter a less free but one more favourable to its percolation to greater depths. Hence we deduce the THIRD LAW—*That the freeness of the circulation of water near the surface is directly proportional to the amount of inclination of the beds towards the sides of the hill, and vice versâ; but that the series which severally denotes the quantity that sinks into each of the strata below, must more rapidly converge to zero than when the inclination of the strata is towards the summit.*

Veins and fissures at the time of their formation would somewhat resemble the joints now found in the strata, and the three laws which we have deduced relating to the descent of water in the latter must equally apply to the former, so far as the two classes of phenomena are in accordance with each other. Veins, however, differ essentially in some respects from joints, and those differences are of such a character as to modify the descent

and circulation of water in the interior of the earth. Unlike joints, veins even of the weakest kind extend to unknown depths, and invariably fracture and dislocate the rocks to a greater or less extent. As east and west veins descend they almost invariably have a hading in a direction contrary to that of the side thrown up, and this hade chiefly takes place in the beds of plate. Plate X., Fig. 1, represents a cross section of one of the east and west veins of Alston Moor, and the black line a vein with very little throw: the open spaces between the sides of such veins are generally very straight, and therefore called weak veins. Should however a further displacement occur, say to the extent of six or eight feet, the spaces would be much widened in that portion of the vein comprehended perpendicularly by the sides of hard rock, as shown in Fig. 2. And it should be observed that the pressure exerted against the sides of the vein in the plate beds would generally prevent the softer material of the plate from falling in and filling up the spaces formed in the harder rock.*

This latter section (Fig. 2) very faithfully represents a cross section of one of the east and west veins from which a large quantity of ore has been raised.

Now it is evident that these open spaces agree so far with joints as to promote the descent and circulation of water in a longitudinal direction in the vein; and the laws regulating such

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* If the reader make a section upon a piece of cardboard, similar to Fig. 1, and divide it with a sharp knife along the line representing the vein, by sliding the two pieces upon a table, in such a manner that the cut edges of the cardpaper touch each other, it will be clearly seen how the more open spaces in Fig. 2 are formed. It rarely happens that the cheeks of hard rock forming the walls of the vein are not more or less fractured, and form what miners call strings or leads. It is not, however, necessary to notice these, as they are simply a portion of the vein. In some instances these strings or leads have evidently promoted the flow or descent of water.

circulation in the former apply equally to the latter. They differ however in this important particular, that the fracture in the plate bed, although unfavourable to a circulation in a longitudinal direction, allows the water to percolate it more freely than it can do through the unbroken sheets of plate which underlie the joints in hard strata. Hence, it not unfrequently happens, that levels and other mining works made in such plate beds are often quite dry even at moderate depths beneath the surface. When water begins to ooze out in the forehead of such levels or advanced works, it is generally considered by miners as an indication that they are approaching a vein. And when the veins were newly formed, and before mineral matter was deposited in them, the percolation of water to great depths would be less obstructed than at present.

In a district much broken with quarter point veins or fissures, the quantity of water which sinks below the surface must be considerably more than in a district where veins of a similar character do not exist; and when the inclination of the beds in connexion with them is favourable towards promoting a circulation *to* another class of veins traversing the country in a *different* direction, and containing wider spaces between the cheeks of hard rock, it is evident that the quantity circulating in the latter must be proportionally increased with the number of these intersecting veins or fissures above that which would simply descend in them had such intersections not taken place. Hence it may be stated in general terms as a FOURTH LAW—*That the quantity of water circulating to and in the wide spaces of the stronger veins will be in proportion to the number of weak veins or fissures traversing in a somewhat different direction the rocks of a country.*

We have already observed that the cross veins of Alston Moor rarely contain lead ore, or even much of any other kind

of vein-mineral, in strata above the Great Limestone. Because of their general unproductiveness few exploratory works have been made, and consequently less of their character in the upper strata is known. Their hade in such strata is more regular, and appears to be little influenced by the harder kind of rocks, excepting when they are of considerable thickness. The following section, Plate XI., the whole of which has been constructed from measurements very carefully taken, represents very accurately the hade and throw of one of these veins which contained a rich deposit of ore in the Great Limestone. It differs strikingly from the sections Plate X., where the open spaces represented in the strata above the Great Limestone are much better adapted by their form for remaining open than the long uniform space represented on Plate XI., now filled with douk, mixed confusedly with stony matter which has fallen from the sides of the vein. The cause of the hade in the cross veins being more uniform in such strata than that of the east and west veins is not easily assignable, unless we suppose that they were formed when the strata were less consolidated and of a more uniform consistency. If this supposition be correct, it will furnish an additional argument in favour of the priority of their formation to that of the east and west veins. Below the Great Limestone the cross veins have less hade in the hard strata of limestone and sandstone, and their other appearances likewise conform more to those of the east and west veins.

The intersections of veins of this douky and impervious character with east and west veins, can only be considered as unfavourable to a free circulation of water in the open spaces of the latter as shown in Plate X. But when the cross veins are weak, the obstruction would probably be very slight, especially if the east and west veins are of later date. The inclination of the strata varies more near strong cross veins than when near east and

west veins; and, in accordance with the *third law*, such inclination would either promote a free circulation of water near the surface, or otherwise retard it, and cause it to penetrate to greater depths. The throws of the cross veins are often very considerable, and this circumstance must necessarily have great influence towards promoting as well as preventing,—as the case may be,—the descent of water into any particular stratum. It is evident that the Great Limestone, or any other stratum of hard rock, lying at moderate depths from the surface, and having an inclination to its outcropping, is placed in a more favourable position for water percolating, and also for circulating in a longitudinal direction, than the same stratum thrown down 100 or 200 feet, on that side nearest the water shed of the mountain, as shown in Plate XII. The dyke of clayey matter contained in the cross vein *a b* must render this portion of the dislocated strata still more unfavourable to the circulation of water in a longitudinal direction.

Having shown that the circulation of water in the interior of the Earth is promoted and regulated by certain causes which have a correlation to other causes preventing its descent and circulation, we are now in a position to affirm the FIFTH LAW,—*namely, that in all localities those reciprocating causes must exist—the intensity of the effect produced by the one set is continually diminishing, as that of the other is continually increasing, and vice versâ; but that in a district traversed by powerful cross veins, the variations and counter-changes must necessarily be the greatest and most abrupt.*

The descent of fluids below the earth's surface in any particular district is also dependent upon the character of the alluvium which covers up the rocks. Some of the thick beds of sandy clay are certainly more adapted than thin loose soils to

prevent the water from flowing over the surface, and to allow it slowly to percolate in greater quantities the rocks below. It is obvious that such conditions cannot be reduced to definite laws. It is scarcely necessary to point out to the careful reader that the last *four laws* are simply conditions modifying the effect of the *first law*.

CHAPTER IV.

OF THE DECOMPOSITION AND CHANGE EFFECTED ON THE ROCKS FORMING THE SIDES OF VEINS.

The descent of water—the most universal of all solvents—into rocks, and its circulation in them, during long periods of geological time, must necessarily produce a series of changes upon the sides of its channels. Lord Bacon observes "that the great winding sheets that bury all things in oblivion are two: deluges and earthquakes." * Waters in deluges leave monuments of their ravages to be contemplated by many generations; but even these are ultimately obliterated by the gentler touches of its "effacing fingers." Nor have we any reason to suppose, that by the still more gentle contact of immersion, the hardest substances would remain unaffected by its action in those dark chasms, where it must unremittingly and in silence have carried on its Læthean operations of oblivion and change, ever since the mountains emerged from the deep. The quantity, however, which sinks under ordinary circumstances is small, compared with that which flows over the surface. In the latter case, the freeness of its action and consequent amount of effect, in dis-

* Of Vicissitude of Things.

integrating the same class of rocks, far exceed that of the former; besides, the rocks are not only submitted to chemical influences, assisted by great variations of heat, but are also ground down by its mechanical action; in the former case, the rocks are subjected to chemical influences only, and in a uniform temperature are softened, dissolved, and ultimately carried away in springs of purest crystal, and other substances brought to supply in some measure the place of that which has been removed, and to blend with that which has been softened and permeated with water.

The air we breathe contains oxygen and nitrogen in the proportion of 20·8 of the former to 79·2 of the latter, and in addition a portion of watery vapour and carbonic acid gas. The carbonic acid in elevated districts, where it is found, probably amounts to about $\frac{1}{3000}$ of the whole. "This small portion of carbonic acid in the atmosphere affords an important part of the food of plants, and the watery vapour aids in keeping the surfaces of animals and plants in a moist and pliant state; while in due season, it descends also in refreshing showers, or studs the evening leaf with sparkling dew."*

The atmosphere also contains other substances. Nitric acid is formed in it by electricity, and certainly some ammonia as well. Humboldt observes that "the admixture of carbonate of ammonia in the atmosphere may probably be considered as older than the existence of organic beings on the surface of the earth."† Many other substances must exhale from the surface of the earth, to return to it again, after having mingled with the condensed particles of water floating in the atmosphere. The consequence is that rain water is never found in a state of purity. "The purest water which can be found as

* Johnston's 'Agricultural Chemistry,' p. 34.
† 'Cosmos,' vol. i., p. 317.—Bohn's edition.

a natural product, is procured by melting freshly fallen snow, or by receiving rain in clean vessels at a distance from houses. But this water is not absolutely pure; for if placed under the exhausted receiver of an air-pump, or boiled briskly for a few minutes, bubbles of gas escape from it. The air obtained in this way from snow water is much richer than atmospheric air in oxygen gas. According to Gay-Lussac and Humboldt, it contains 34·8 per cent. of oxygen, and the air separated by ebullition from rain water 32 per cent.*

Under the ordinary pressure of the atmosphere, carbonic acid gas enters into combination with water in about equal volumes; all rain water therefore contains a portion, "and after heavy rains the moist state of the ground diminishes the quantity of the gas, apparently by direct absorption." † Indeed all the different substances floating in the atmosphere must be precipitated in rain upon the surface of the earth, or absorbed directly by the living organisms of plants and animals and other chemical products forming there.

If water in the atmosphere contains impurities they must be increased after its precipitation on the earth's surface. From decaying vegetation and putrid animal matter an extra quantity of carbonic acid as well as ammonia must be derived. A large portion of each is absorbed by the roots of growing plants, and thus from the ashes of living organisms Nature ever produces new life. Coleridge observes that "the metal at its height of being seems a mute prophecy of the coming vegetation, into a mimic semblance of which it crystallizes." The relation of vegetables and minerals may not consist in a mimic semblance only; it may be that the same kind of particles in different combinations enters into the composition of both. It is certain

* Turner's 'Chemistry' (sixth edition), p. 256. † Ibid., p. 268.

that in each case the substances of which they are composed are derived from the crude and heterogeneous masses of inorganic matter constituting the crust of the globe. It would appear, therefore, that their various properties or attributes, which enable us to become cognizant of their existence, are the result of the organization of a few simple substances according to chemical and in the case of vegetables to semi-vital laws regulating the formation and ascent of sap. Minerals, like vegetables, are also subject to decay; and could we watch, through indefinite periods of time, the processes of formation and corrosion, we might apply to them the beautiful language of Spenser:—

"For all that from her springs, and is ybredde,
However fayre it flourish for a time,
Yet see we soone decay; and, being dead,
To turn again into their earthly slime:
Yet, out of their decay and mortal crime,
We daily see new creatures to arize,
And of their Winter spring another Prime,
Unlike in forme, and chang'd by strange disguise:
So turn they still about, and change in restlesse wise." *

The action of water upon inorganized matter at the surface of the earth is perhaps in all cases detersive, but as it sinks to greater depths its action appears to be modified, probably by some chemical change upon the various substances it holds in solution. Its detersive effect also extends below the surface to varying depths, the extent of which is regulated by circumstances, its action being chiefly restricted to the decomposition of all kinds of rocks as well as all other mineral substances.† At greater depths its action appears to be not only detersive but also reproductive, other substances being often brought by it to

* 'The Faerie Queen.'

† It was somewhat fancifully supposed by the mystical school of Biologists, "that all things are alive, eat, drink, and excrete; even minerals and fluids."—Whewell's 'History of Scientific Ideas,' vol. ii., p. 175.

supply to some extent the place of those that have been removed.

It is no doubt owing to the wasting of the limestone rocks by the percolation of water through them that the *wide* spaces in the joints are due; certainly not to any contraction of the limestone by a consolidating process taking place after its exposure to the surface, since, as before observed, the limestone at great depths, where no joints are found, is equally hard and consolidated, and even more so than that near the surface. If the hypothesis previously hazarded respecting the formation of joints be admitted—namely, that they are due to the expansion of the hard limestone and sandstone rocks vertically, after the denudation of the superincumbent rocks and the consequent withdrawal of their particles laterally, corresponding to some lines of least resistance previously affected on the rocks by crystalline action, when they were sunk far below the surface—then there can be no doubt entertained, but that water and the other substances it holds in solution entering into these small fractures would, by their solvent properties, decompose the hard rocks forming their sides, and during a long course of geological time, being slowly enlarged, they would assume the appearance of wide joints, as seen in precipices and scars, and which are so well known to every observer and admirer of rocky scenery.

We have observed above, that the effect of water on the surface is always wasting, never reproductive. The formation of sheets of tufa, or travertine, by springs holding bicarbonate of lime in solution, may seem to be an exception; but it can hardly be considered so. It simply proves, that concentrated solutions flowing to the surface in springs of mineral waters, may be precipitated in quantities greater than can be removed in the same time by the wasting effects of atmospheric agency. Rocks formed in this manner only occur where such springs

issue to the surface. No broad extent of country like Alston Moor could ever be covered by sheets of tufa or travertine, although minor patches of these are by no means uncommon. Such rocks, like all others, are equally subject to decomposition after the springs cease to flow, or, changing their direction, issue to the surface in some other locality. Sir Charles Lyell, however, observes that "those persons who have merely seen the action of petrifying waters in England will not easily form an adequate conception of the scale on which the same process is exhibited in those regions which lie nearer to the active centres of volcanic disturbance."* But from this author, we are led to infer, that the extended sheets of travertine in the volcanic districts of Italy have been deposited in the bottom of extensive lakes only; similar to the depositions that must be going on at the present time in the lake of Solfatara. In the volcanic districts of Central France the matter deposited by the calcariferous springs appears to be limited even to small portions of the gorge in which they flow; the more uniform and extended sheets of limestone, which resemble the Italian travertine, having originally been deposited in the ancient lakes, fed by waters derived from springs of this character. On the 22nd page of Mr. Powlett Scrope's second edition of his geology of this district there is a description of a deposit from a petrifying spring 240 feet in length, and also a beautiful illustration of its termination as a natural bridge, 16 feet high and 12 feet wide, thrown across one of the streams near Clermont.

To the decomposing effects of meteoric agents at and a little below the surface, the contents of veins are equally subject as the enclosing rocks, and in many cases even more so. The sulphides of lead and zinc are changed into carbonates. The

* 'Principles of Geology' (ninth edition), p. 240.

sulphur oxidizes and passes away as sulphuric acid. The oxides of lead and zinc are then attacked by carbonic acid, and carbonates are formed. Ultimately, however, both are dissolved and carried to the surface by the circulating water. The time necessary to effect the transformation of sulphide of lead into carbonate does not appear to be long where carbonic acid exists plentifully. In peat moss where lead ore has occasionally been accidentally placed, a period of fifty or sixty years, or even less, is sufficient to produce a coating of carbonate of a very perceptible thickness. Sir H. De la Beche states that in the very old workings of the Derbyshire mines, some of which may reach back 1700 years, the small pieces of sulphide of lead, found in the old refuse, are wholly changed into the carbonate, and the larger pieces are thickly coated with the same substance. The water in which this change has been effected usually contains much bicarbonate of lime in solution.* In some of the very old mines in Alston Moor the same effects have been observed.

We shall not at present take into consideration the particular cases where metallic matter may have been wholly or partially decomposed and removed from the veins of Alston Moor, but endeavour briefly to point out the general conditions which have modified the action of the decomposing agents.

Limestone strata, when lying in broad plateaus with other strata thinly superimposed, and their basset forming precipitous cliffs along the sides of the valleys, are placed in a situation favourable to decomposition by atmospheric agency, and, as already pointed out, are much broken with joints. In such a position, it is evident that the metallic substances, deposited in the veins, would be gradually removed by the percolation of water containing common air and other substances held in

* 'The Geological Observer,' p. 794.

solution, after the denudation of the sides of the valleys had brought the rocks and the veins formed in them under the influence of such decomposing agencies. The consequence is that veins in such localities are generally destitute of rich deposits of metals, or, in the language of the Alston Moor miners, termed "broken," and the "strata unsound," and such grounds are considered unfavourable to successful mining operations. The broken and unsound character of the veins and rocks is not, however, the cause of the absence of metallic substances, as the miners suppose, but only a condition favourable to the wasting operations of meteoric causes, as rich deposits of lead ore have been found in such situations, but then, almost invariably under thick beds of clay, or where the decomposition has been arrested by the filling up of the interstices of the veins and rocks with clay, or iron oxides, or some conditions tending to preserve the sulphide of lead from meteoric influences.

As water descends to greater depths, its decomposing character is modified: so much so that, while one kind of substance subjected to its influence is decomposed, another is not prevented from being deposited, or the materials of the former are remodelled under different conditions of existence. To attempt to demonstrate synthetically the cause of this modification, in the effects of water as it descends below the surface, is certainly not my province. I wish to call the attention of the chemist to the fact that water, as it falls upon the surface of the earth, contains something promoting changes which end in sulphides of lead, zinc, or iron, being converted into carbonates, but after it has descended to some depth, these sulphides are not effected in the slightest degree. Dr. Daubeny has drawn attention to the small quantity of oxygen that is intermixed with the waters of thermal springs.* I apprehend that this

* 'On Volcanoes,' p. 561.

equally applies to the waters, whether thermal or not, which circulate in the fissures of stratified rocks at even moderate depths below the surface. Nor does the supposition of Professor Rogers seem at all improbable, that the absorption of the oxygen is due chiefly to protoxide of iron, since iron exists plentifully in all beds of shale. Can therefore the difference between the effects of water at the surface and the interior of the earth be owing to the greater quantity of oxygen intermixed with it in the former case, which in the latter is absorbed by the rocks, as it descends through the fissures?

We have already stated that rain water, when precipitated upon the earth, contains a portion of carbonic acid which increases its solvent properties, and promotes the decomposition of the rocks at or near the surface. The part it plays, however, is not confined to the production of chemical effects near the surface; it appears as one of the great agents of change at very considerable depths, certainly as far into the interior of the earth as mining works have been extended, and probably as far as water ever penetrated when the fissures through which it descends were first formed. Dr. Daubeny, while allowing that common springs often give off carbonic acid gas, seems to limit its existence in large quantities chiefly to volcanic districts, or to those lines of upheaval or fractures which, extending to great depths, allow it to ascend.* It, however, exists only too plentifully for the health and comfort of the miner, in the veins of Alston Moor, where the conditions are of such a character as to preclude all idea of its ascending from great depths.

In levels, driven in solid plate, perfectly compact and free from open spaces, the air becomes highly charged with this gas, so that it becomes imperatively necessary to supply the work-

* 'On Volcanoes,' p. 563.

men with pure air, forced through wooden boxes, or cast iron pipes, in order to neutralize its noxious effects. It is not only levels in plate beds, but all advanced works, that need to be supplied in this manner with pure air. Nor is it an uncommon occurrence, for the intermediate space between the point where the pure air enters the pipes, and that to which it is conducted, to be filled with this gas to such an extent that candles will not burn; while at the level foreheads, &c., the workmen carry on operations of blasting, &c., without difficulty.

A few years ago, an attempt was made to form a communication with the surface, in order to ventilate a portion of Long Cleugh mine at Nenthead. The total thickness of the strata between the highest level and the surface amounted to 336 feet. To effect this object, it was determined, in the first instance, to make a Rise from the level, as high as it could be conveniently extended, and afterwards to sink a Shaft from the surface to communicate with it. The Rise, after ascending 90 feet, reached the Firestone stratum (Plate I., No. 20), and drained from it a very considerable quantity of water, which continued to flow regularly in connexion with a large quantity of carbonic acid gas. Much pure air was forced up the Rise by a powerful ventilator; but it availed little in counteracting the noxious effects of the gas. The operation of rising could, therefore, only be carried on under great difficulties and much loss of time, and had ultimately to be suspended.

The operation of sinking from the surface was even less successful than that of rising. After attaining a depth of 54 feet, the quantity of water which flowed into the Shaft was so great that it prevented further operations. It was then determined to communicate with the Rise-top by boring through the remaining portion. The boring had to be made through the Slate Sills and several beds of plate. After it reached the High Slate Sill the water

flowed from the Shaft and borehole into the joints of that stratum. Ultimately the Firestone stratum was reached, when, with great violence, the water ran out of the borehole, and flowed down the rise. The quantity which continued to flow for a few weeks was sufficiently large to turn a moderately-sized over-shot wheel. Water still continues to flow, though in a much less quantity than formerly. The quantity of carbonic acid gas is, however, so much increased that it is only occasionally, in some peculiar state of the weather, that a lighted candle can be carried to the bottom of the Rise, which is situated only a few feet from a circulation of pure air.

At the present time, the quantity of water dashed down the Rise amounts to 24 gallons per minute; it must, therefore, carry off a large portion of the latter in solution. From the higher specific gravity of carbonic acid gas over that of common air, a portion probably settles into the lower parts of the mine, or mingles with the moist air, and is ultimately borne by the circulation of the latter to the surface. It is not easy to point out the source of such a large supply of carbonic acid gas, but assuredly it is not due to exhalations from great depths. There exist, at the surface, widely extended beds of peat, which in some places are 10 feet thick: it is perhaps from the decomposition of these that a portion of the carbonic acid gas is derived.

In another part of the same mine, situated 420 feet below the surface, and about one mile from the entrance, a Sump was in the course of being made into the Great Limestone, in order to find deposits of lead ore in Long Cleugh vein; when several small caverns connected with the vein were broken into, from which carbonic acid gas issued, accompanied with a hissing noise. The miners filled up the caverns with stiff clay to prevent the gas from flowing out, but in vain, for it made an opening through the clay; and in one place threw up the water

with considerable force. In order to explode a blast, one of the workmen was let down the Sump to relight a match which the gas had extinguished, when he nearly lost his life, so large was the quantity of gas which had flowed into the Sump in the course of a few minutes. It is remarkable that much rain fell afterwards from a very murky atmosphere. Generally there is a close connexion between certain states of the atmosphere and the supply of this gas in the mines. It frequently flows out of the caverns and other small openings in the veins in a manner very similar to water. There is, however, this difference,—water can be heard and seen trickling down the sides, whereas carbonic acid gas is generally noiseless and always invisible. A lighted candle placed within one inch of the gas as it flows from the crevices often burns brilliantly, but when removed this short distance into the stream, it is instantly extinguished.

Before levels and other horizontal openings were made, the open spaces in the veins were doubtless filled with water, holding carbonic acid *in solution*, since it is evident that the latter can only assume the gaseous form after the veins are drained. Occasionally the same results would be effected by natural openings to the surface, through which the water would issue in the form of springs. But in Alston Moor it is only portions of the veins near the surface, that have been drained naturally, and in most instances this is due to joints in the limestone strata.

The quantity of carbonic acid gas absorbed by water is in exact ratio to the compressing force; that is, water dissolves twice its volume when the pressure is doubled, and three times its volume when the pressure is trebled.* It does seem probable that in many places below the earth's surface, compound pro-

* Turner's 'Chemistry,' p. 294.

portions of this gas must be absorbed by the water. In consequence, the disintegrating effects produced by such combinations of these corroding substances, upon all kinds of rock, but more especially upon limestone, are materially increased. Sir Charles Lyell observes "that many springs hold so much carbonic acid in solution that they are enabled to dissolve a much larger quantity of calcareous matter than rain water."* All rocks in which felspar enters as a constituent part are liable to be decomposed by a combination of carbonic acid and water; and by their joint action, the oxides of iron are rendered soluble, and entering into combination with them flow to the surface, where they issue as springs of chalybeate water. The eminent author just quoted states that "in the environs of Pont Gibaud, not far from Clermont, a rock belonging to the gneiss formation, in which lead mines are worked, has been found to be quite saturated with carbonic acid gas, which is constantly disengaged. The carbonates of of iron, lime, and manganese are so dissolved, that the rock is rendered soft, and the quartz alone remains unattacked."† In veins, specimens of pure quartz crystallized are often found lying quite detached in the crevices and smaller caverns, and especially when their walls are formed of limestone rock. I have now in my possession a nest of quartz beautifully crystallized in the interior. It was found lying quite loose in a small cavern in a vein; at one period the quartz had evidently been attached to the limestone, and was probably disunited from it by the disintegrating effects of water holding much carbonic acid in solution.

The action of water and carbonic acid upon the rocks forming the sides of veins in Alston Moor, is no less remarkable than that undergone by the gneiss rocks in the lead mines of Cler-

* 'Principles of Geology,' p. 239.

† On the authority of Ann. Scient. de l' Auvergne, tome ii., June 1829.

mont. Near the veins, limestone rock has evidently been subjected to some rearrangement of its particles, giving it a crystalline structure, which it originally does not possess. In many instances, it evidently contains a proportion of carbonic acid greater than is found in pure limestone, and which could only enter into combination with it when in a softened state. In this case, it is more indurated than common limestone; but from the disengagement of the carbonic acid, it decomposes more rapidly in the open air. The limestone is also often impregnated with iron, diffused throughout the whole mass, in such a manner as could only occur when the limestone was in a soft or porous condition. On the south side of Rampgill vein, in the Fell-top Limestone, to such an extent has this rearrangement and substitution of particles taken place, that it is now converted into a rich ironstone, which has been carted a distance of upwards of five miles to Alston, and afterwards conveyed to Newcastle by rail. Such changes and rearrangement of particles in limestone rocks are well worthy of being submitted to chemical investigation.

The limestone strata are divided horizontally by thin beds of argillaceous shale. Some of the layers are more susceptible of decomposition and change than others; and from this circumstance they are termed flat posts. The Great Limestone contains three posts of this character, respectively termed the High, Middle, and Low flat. In the Scar and Tyne bottom Limestones, posts more susceptible of decomposition than the rest are also found to exist. When near to veins, the latter limestone has undergone a greater degree of change and decomposition, throughout its entire thickness, than any other in Alston Moor.

Near veins, large caverns are frequently met with in limestone strata, more particularly in these flat posts. They are often beautifully lined with crystals of various kinds of spar, but occa-

sionally they present a jagged or corroded surface, with no lining of spars. A few years ago one was found between two portions of Long Cleugh vein, in the High and Middle flat posts, that contained twenty cubic fathoms of open space, all lined with galena, Black Jack, and carbonate of lime. Caverns of lesser dimensions than this are by no means uncommon; they are, however, seldom found larger. Where they occur in the Nenthead mines, the limestone is a compact mass entirely free from joints or any fissures except veins. It is not an uncommon circumstance to find a sandy residue left in the bottom of these caverns, which is sometimes slightly cemented into a porous mass, not unfrequently containing perfect crystals of galena.

The caverns are, however, generally small, and had no mineral matter been deposited in them, the limestone had presented a very honey-combed appearance. Most of the caverns are elongated in a horizontal direction, and the very thin seams of argillaceous shale, which may occasionally form their roof, remain undisturbed. Upon the section, Plate XIII., showing the position of the strata between Small Cleugh and Handsome Mea Great Cross vein it is attempted to delineate a flat on the west side of the latter vein; the black lines represent the beds of shale dividing the limestone into horizontal layers, or posts. It shows the flats as they are usually met with in the Great Limestone stratum. In this instance the west side gradually merges into pure limestone, and the portion most corroded lies near the cross vein. Occasionally flats terminate abruptly at strings or even very weak leads connected with some of the veins. When lead ore occurs in flats, it is found deposited in these caverns, and sometimes gives the flat a seamy appearance, especially when the caverns are almost filled with pure sulphide of lead. In the formation of flats the quantity of limestone changed or transported from many places is very great. The Small Cleugh

flats are represented on the Plano-section, Plate XIV., and do not occupy an area less than eight acres, three of which have probably been worked for the lead ore deposited in them. They are chiefly situated in the low flat post, which is fifteen or sixteen feet thick; consequently in this post alone not less than 5,000,000 cubic feet of limestone have undergone decomposition and rearrangement of its particles, besides the large quantities which have undergone similar changes in the middle and high flats. The decomposing agents have originally entered the limestone through very weak north and south running leads. These leads are connected with the cross veins, and their width scarcely equals that of a penny piece. The east and west leads shown upon the sketch are simple openings or cracks often unfilled with mineral matter. They cut through the galena, spar, &c., deposited in the cavernous parts of the flat; and a proof of their recent formation is derived from the fact that they have not modified the action of the decomposing forces in the slightest degree. The greatest amount of change and decomposition has been effected near to Handsome Mea Cross vein, where also carbonate of iron enters more abundantly into the composition of the limestone remaining *in situ*. Near to this vein, carbonate of iron is also more plentifully deposited in the caverns.

In the Tyne bottom mines more of the Tyne bottom Limestone has been affected by decomposition than that of the Great Limestone described in the instance above; but in the Tyne bottom mines larger portions of the flatted limestone are unworked, the lead ore not being so plentifully diffused through the mass as to repay the cost of mining. Flats are also found in this limestone in various other localities, but none as yet have been discovered in Alston Moor as extensive as those in the Tyne bottom mines. Those which have been worked in the Ashgill Field mines are represented upon the sketch Plate XV. No

very large quantities of lead ore have been at any time produced from them.

The Scar Limestone, when removed from the surface, has perhaps suffered less change from aqueous and other decomposing agents than either the Great Limestone or the Tyne bottom Limestone: at all events, flats containing ore in sufficient quantities to repay the cost of mining are not so often found. In Alston Moor the principal flats which have been worked for lead ore occur in the Ashgill Field mines, and are represented on the sketch Plate XV. by three or four patches of shaded space, *a*, *b*, *c*, *d*. In connexion with these flats there are considerably more intersecting strings and leads than in the Small Cleugh flats. The flat *a* was cut off abruptly at the east end by a weak quarter-point vein. No doubt can be entertained but that these weak veins and leads have afforded a passage for the decomposing fluids into the heart of the limestone at a period long anterior to the formation of the joints which now exist; since joints have not influenced the action of the decomposing agents in the slightest degree, although in consequence of the flats occurring so near the surface many of them are found in the limestone. Veins and flats in this stratum near its outcropping often contain brown oxide of iron; for instance, in the neighbourhood of the Nest and Manor House, Lowbyer, it occurs sufficiently rich to repay the cost of working and carriage by rail to Newcastle.

Flats of considerable extent are found in the Great Limestone in Dowgang mines at Nenthead. At one particular place they are connected with a strong vein, which dislocates the strata considerably. This vein leaves the principal Dowgang vein in a north-west direction, and shortly afterwards begins to divide into separate portions, to such an extent, that before intersecting Dowgang East Cross vein (see Map) it exists only as a widely diffused group of strings and leads. In these mines a very

great quantity of limestone has been subjected to decomposition and change. In the Holey Field mines, in the same stratum of limestone, extensive flats are found in the walls or sides of the veins. In these flats some large caverns were found which contained rich deposits of lead ore.

Flats of considerable extent are connected with the veins in Rampgill mine, particularly in the group of sun veins on the west side of Rampgill cross vein, and on both sides of the latter vein about the places of intersection with the sun veins. In connection with Rampgill vein large quantities of limestone have undergone decomposition and change where no lead ore has subsequently been deposited. In the east portion of the mine, and on the south side of Rampgill vein, the flats which have been worked for the ore they contained are chiefly connected with quarter-point veins.

Much change has been produced upon the Great Limestone forming the sides of Scaleburn vein. The decomposition in many places extends to a considerable distance on each side. Extensive mining works have been made in these flats to procure the lead ore deposited in them, but on account of their very hard character much flatted ground remains unworked, the lead ore deposited in them being too small to repay the cost.

In the Coal Cleugh mining district the limestone strata have undergone similar changes, and the quantity so acted upon is indeed very great. The mining works made in these flats are extensive, and very large quantities of lead ore must have been produced from them, as scarcely any doubt exists of their having been worked, to a greater or less extent, for the last hundred and thirty years.

It is unnecessary to notice further a phenomenon found to be connected, in some degree, with all the veins of Alston Moor.

Even where flats are not formed, limestone cheeks of veins have in all cases undergone change and rearrangement of their particles. Indeed, no mineralogist or geologist could view the corroded and hardened state of the limestone near to veins in the mines of Alston Moor without being deeply interested. Such observations, however, are best made as the mining works advance, since they frequently remain open for a short time only, and are then closed up for ever. Sometimes the phenomena remain open to inspection, more particularly where the levels or open drifts happen to be made in some of the flat posts of the limestone strata.

In sandstone strata the effect of the decomposing agents is less striking. Occasionally, however, in such strata small caverns are found on the sides of veins, which are evidently formed by the disintegration and dissolution of the rock. In these caverns sandy residue often remains at the bottom. In the vicinity and interior of veins sandstones as well as limestones have suffered considerable change in their constituent parts, the former, however, not to the same extent as the latter. Under such circumstances the sandstones are more indurated than the same kind of rock situated at some distance from veins. Sometimes strings of pure sulphide of lead are found in sandstone, which in appearance at least has undergone no change or transformation of its particles.

Such is the nature of the effects produced by erosive fluids upon rocks, not only at the earth's surface, but far down in its silent depths. Substances so hard that they can only be penetrated by the art of man, and at a great cost of labour, are slowly disintegrated, the tombs of myriads of zoophytes and mollusca are ruthlessly opened, and by the unremitting action of subtle fluids, their marble monuments vanish as surely as the snows of April. Even these exist not as the invari-

able. Metals of all kinds are equally if not even more subject to change. After their deposition in one place they are dissolved and transported to other localities, it may be to assume the same conditions of existence, or perhaps to enter into other combinations in which there are no indications of the changes previously undergone by them. The transformations of iron are better known than any of those of the other metals, and they have been pointed out in such a forcible manner by the late Hugh Miller that I cannot forbear giving the passage entire, as a proper conclusion to this chapter and an introduction to the next. "How strange, if the steel axe of the woodman should have once formed part of an ancient forest!—if after first existing as a solid mass in a primary rock, it should next have come to be diffused as a red pigment in a transition conglomerate,—then as a brown oxide in a chalybeate spring,—then as a yellow ochre in a secondary sandstone,—then as a component part in the stems and twigs of a thick forest of arboraceous plants,—then again as an iron carbonate slowly accumulating at the bottom of a morass of the coal-measures,—then as a layer of indurated bands and nodules of brown ore underlying a seam of coal,—and then, finally, that it should have been dug out, and smelted, and fashioned, and employed for the purpose of handicraft, and yet occupy, even at this stage, merely a middle place between the transmigrations which have passed and the changes which are yet to come."*

* 'The Old Red Sandstone,' p. 251 (seventh edition).

CHAPTER V.

OF THE DEPOSITION OF VEIN MINERALS AS CARBONATE OF LIME, BARYTES, ETC., IN THE OPEN SPACES OF VEINS.

In the preceding chapters of this book, we have attempted to point out the conditions regulating the descent of water into the interior of the Earth, in mountainous districts and through stratified rocks. It has also been stated that it must carry with it carbonic acid, and probably other substances, which in combination are calculated to dissolve some of the hardest rocks, and that, in the fissures or channels through which water and its contained substances descend at the present time, certain phenomena of decomposition and transformation are found, which can only be effected by erosive fluids. We have also shown that the quantity of rock transformed or borne away bears some proportion to the solubility of the rock itself, and to the number of channels through which the erosive fluids descend, or by means of which they permeate the rocks. In sandstone, as might be expected, the phenomenon of change, &c., is much less strikingly exhibited than in limestones; the former being less soluble in carbonic acid than the latter. We have also pointed out the improbability, if not the impossibility of erosive fluids ascending from great depths. We are therefore

justified, from this circumstance in connexion with the effects produced, to conclude that the decomposing agents are entirely derived from the atmosphere and the earth's surface.

We previously pointed out the proportions of limestone, sandstone, and shale, whose aggregate thickness forms the Lead-measures of the Mountain Limestone strata of Alston Moor and the adjacent mining districts. We shall now proceed briefly to inquire into the connexion (if any exist) between the different kinds of rock and the deposition of ordinary vein minerals. As these rocks have all undergone decomposition, particularly the limestones, it will naturally be supposed that deposits from such solutions, in different combinations, ought to be found lining the sides of the cavities or fissures: in short, that quartzose substances and the various kinds of carbonates of lime and iron ought at least to be found in the veins.

We have already shown, that on account of the hade of the east and west veins taking place chiefly in the beds of shale, the sides of the veins in such soft strata approach each other, and the little space is often filled with a soft clayey matter. It has also been stated that water percolates the veins, in a downward direction, when filled with this clayey substance, but that the circulation horizontally must take place chiefly in the open spaces comprehended between the cheeks or sides of sandstone and limestone. Now, as the water which circulates in such open spaces holds a quantity of decomposed matter in solution, derived from the sides of its channels, the question arises, does the mineral matter deposited on the sides of the veins in any particular stratum, bear any relation in kind to the enclosing rock?

In the strata, included between the Grindstone Sill and the top of the Little Limestone (see Plate I.), the quartzose substances deposited in the veins are much less than might

be expected from the silicious nature of the rocks. Indeed, fluor spar (fluoride of calcium), carbonate of lime, and sometimes the oxides of iron are the prevailing minerals. The carbonates of lime occur crystallized in various forms, and generally, the crystals of all these minerals are found in the greatest perfection where the largest quantities of lead ore are deposited. It seems probable, that the lime is separated from the sandstone, in which it exists as a cement, holding together the small particles or grains of quartz. But it is not so easy to point out the source of the fluorine with which it has entered into combination. It has however been proved by Dr. George Wilson that fluoride of calcium may almost always be found in those waters which contain bicarbonate of lime, and also in most sedimentary rocks and alluvial soils. The waters which issue in springs from the base of the Slate Sills and other thick beds of hazle, almost invariably contain bicarbonate of lime, and also some iron in solution.

In the Nenthead district, and in the Little Limestone stratum, veins frequently contain much blende and iron, and also a greater proportion of quartz than in the sandstone strata above. Fluoride of calcium and carbonates of lime are by no means uncommon in this stratum of limestone, and in the Coal Sills below. Generally some considerable amount of quartz is found in connexion with the sulphide of zinc. The converse, however, does not follow; since veins almost entirely filled with quartz often contain no sulphide of zinc.

In the Great Limestone stratum, a greater variety of minerals is mingled together in the veins than in any of the strata above. In the Nenthead mines, however, fluoride of calcium is rarely met with in considerable quantities. At some former period it must have been plentifully deposited in the veins of this district, since casts of its crystals in quartz are by no means uncommon, even in veins where not the smallest particle of the substance

M 2

can now be found. At Garrigill, in the Cowper-dyke-head's mines, carbonate of lime and fluoride of calcium exist plentifully in the Great Limestone, the veins being almost filled with these substances. A narrow stripe of ore generally lies against the limestone, and the rest of the open space originally formed in the veins is filled with these sparry substances, containing nodules of sulphide of lead. Sometimes the centre of the sparry mass is cavernous, with crystals of fluor spar lining the sides of the open space; the filling of the vein is then represented by the section Figure 1, Plate XVI. In the Weardale and Allenheads districts the veins in all the strata are chiefly filled with lead ore, carbonate of lime, and fluor spar: in this respect they differ very materially from the veins in the Nenthead and Coal Cleugh mining districts. From the circumstance of the veins in the latter districts having once contained this mineral, where none of it now exists, it may be inferred, that the vein deposits have undergone some great change, from which those in the Weardale and Allenheads mines have been exempt. The veins in the last-named districts differ also from those in Alston Moor in not containing much sulphide of zinc.

In the *sandstones* below the Great Limestone, the east and west veins generally contain more quartzose minerals than in the Slate Sills, Firestone, &c., or even in any of the veins in the Great Limestone. In the Nenthead district, so far as the veins have been proved in such strata, the sulphide of zinc disappears, at least it rarely occurs in masses as the principal mineral in the veins, though crystals of it, deposited upon the carbonates of lime and iron, when such occur, are not unfrequent. Quartz, however, is not the predominating mineral in all the strata below the Great Limestone, since both the east and west, and north and south veins, occasionally contain so much carbonate of lime, in the limestone strata, as to be almost

filled with it. For instance, in Carrs vein in Lovelady Shield mine, and also Black Ashgill cross vein in the Four-fathoms Limestone, immediately below a very rich deposit of lead ore in the Great Limestone. In this latter instance, the rhombohedral cleavage, so characteristic of calc-spar, is very distinct. A number of the veins proved in the Scar Limestone from Nentforce level, appears to be filled with carbonate of lime. In this stratum Guddamgill vein contains not less than three feet wide of this substance. Hudgill Burn cross vein (a continuation northward of Black Ashgill cross vein), contains an equal width of it in the same stratum.

Both east and west and north and south veins in the Scar Limestone, at its outcropping near the banks of the Tyne river in Garrigill, seem to be filled in a great measure with a hard kind of quartz rider which has not, as yet, ever been found connected with much lead ore, although small particles of it are very frequently blended in the rider with crystals of quartz. This kind of quartz rider may easily be seen at the surface where Benty Field vein crosses Garrigill Burn near the road between Alston and Garrigill.

The veins which have been worked for lead ore in the Tyne bottom Limestone, often contain much carbonate of lime, though quartzose minerals are by no means uncommon. In the flats, in this stratum, the former occurs beautifully crystallized in various forms. In the Tyne bottom mines six-sided prisms were often found three or four inches long and scarcely more than one-eighth of an inch in diameter. These prismatic crystals are formed in small caverns in the flat, and are found sometimes crossing each other, or more frequently arranged regularly like the quills upon the porcupine's back. These beautiful specimens were found in the greatest perfection where the flats contained the richest deposits of lead ore, but it was

scarcely possible to obtain undamaged specimens out of the small caverns. In connexion with these specimens of carbonate of lime many excellent ones of quartz occurred, often splendidly crystallized; also some chalcedony, and much iron pyrites. In some parts of the same mine fluor spar is found in very clear and fine crystals, generally very small, and deposited upon such a brittle base that the specimens obtained rarely exceeded a cluster of two or three crystals. Occasionally these crystals of fluor contained a small cavity in the centre, filled with water.

In the Tyne bottom mines, some proof of the veins in the underlying Basaltic rock has been made, in which stratum they are filled with calc-spar and some carbonate of iron, but contain no lead ore. Their contents are similar to the minor veins in the igneous rocks of Derbyshire which, as Sir H. De la Beche observes, are often filled with calcareous spar.* One or two veins at the surface, in the Whin Sill near Tynehead Smelt Mill, are filled with a very hard silicious veinstone, not at all mixed with lead or any other kind of ore except iron.

On the west side of the Tyne, in the beds below the Great Limestone, the veins seem to be filled either with carbonate of lime and fluoride of calcium, or with quartzy spar. Where lead ore occurs plentifully, it is always accompanied with fluor spar, though fluor spar occasionally exists where very little lead ore is deposited.

Looking at the facts connected with the subject generally, the distribution of vein minerals whose specific gravity is lighter than the ore of lead—and the elements of which are thought to be derived from the decomposition of the rocks forming the sides of the veins—is apparently subjected to less law and order

* 'Geological Observer,' p. 766.

than perhaps might be expected. Veins in one locality may be filled with carbonate of lime or fluoride of calcium, but the same veins in the same strata may be filled in a great measure with quartzose substances, which are generally much crystallized, the crystals being often very small. It may, however, be stated, very generally, that in those portions of the veins, where the conditions are favourable to a free percolation and circulation of fluids, the greatest variety of minerals is found, and those crystallized in the greatest perfection. On the contrary, when the conditions are unfavourable to a free circulation, the veins are filled either with amorphous carbonate of lime, or quartz, or in some instances with fluoride of calcium. Under such circumstances long continued, and keeping in mind the abundance of carbonate of lime held in solution, it is not surprising that lime should have occasionally been thrown down so abundantly as to fill up the entire space in the veins. That quartz may be formed under quiescent conditions, is also evident, from the fact of crystals of this substance having been formed in a phial charged with silicious particles kept undisturbed for years.* From this it would appear probable, that the veins in the Scar Limestone in Garrigill have been mineralized before the Tyne river cut its bed through this stratum of limestone, and since then, the contents of the veins have not been subjected to any great law of change.

Many changes, however, occur for which it is not easy to assign a mechanical cause; for instance, why the veins in the Nenthead mines should contain much blende, and the continuation of the same veins in Garrigill none. Mr. Forster observes "that the mines (veins) on the east side of the Great Burtreeford Dyke or vein, are generally of a softer nature than

* Mill's 'Logic,' vol. i., p. 421.

those on the west side, as at Allenheads, and all the extensive mines in Weardale and Derwent, which are (situated) on the east side of the Burtreeford Dyke; likewise, that the mines (veins) which are (situated) on the west side of the above mentioned vein, are generally of a harder nature, frequently containing a great deal more of jack and rider, as at Coal Cleugh, all the mines in Alstone Moor and Kilhope, and the mines in Teesdale. . . . . On the east side of the above great vein the veins contain mostly the calcareous or fluor spars."* It is probable that the conditions of mineralization are or have been different on opposite sides of this great vein. On the south-east side the beds incline rapidly from the vein. Mr. Forster also observes that in the Cross Fell mines the veins which are all filled with fluoride of calcium, on the contrary or west side of the mountain contain little else than sulphate of barytes and some galena.† Here, where there are no great dislocations of the beds by cross veins, and where the different portions of the same veins would be subject to mineralizing processes at the same time, their contents differ as greatly as the contents of the veins situated on the opposite sides of Burtreeford Dyke. Sir H. De la Beche observes that, "If in a limestone country, such as the mining districts of Derbyshire, an observer found the successive coatings upon the sides of the veins composed of calcareous spar, he might be led to infer that this substance was derived from the limestone beds, so abundant around, and in which the fissures may be formed, while, if composed of sulphate of baryta, a common mineral in parts of that district, he might be induced to seek other sources of supply. Should the single substance in a vein amid limestones be fluoride of calcium, while he would see that an abundant supply of calcium was at

* 'Section of Strata,' p. 269. † Ibid., p. 276.

hand to combine with fluorine, he might question the limestone having been the source of the latter substance in the quantities found in the veins."* Both Rampgill and Middle Cleugh second sun veins contain barytes (baryto-calcite) in the Grindstone Sill, but not a particle or trace of it in any of the strata below. In such situations, nearly on the top of the hills, it is not easy to conceive from what other source the baryta can be derived than from the enclosing rock; and the presence of this and many other substances of an anomalous character is probably due to laws of chemical combination as yet unknown, but the action of which may be still in daily operation. In Welhope vein, sulphate of barytes is deposited in the upper beds of sandstone, but in the Great Limestone, carbonates of barytes.

* 'Geological Observer,' p. 798.

CHAPTER VI.

OF THE CONNEXION BETWEEN THE CONDITIONS REGULATING THE DESCENT AND CIRCULATION OF FLUIDS, AND THE DEPOSITION OF LEAD ORE IN THE VEINS OF ALSTON MOOR.

THE effect of rocks in modifying the amount and kind of mineral deposit in veins is most strikingly exemplified in the deposition of lead ore, occurring so plentifully under certain conditions, in both limestone and sandstone strata above the Tuft; while the same veins in the limestones and sandstones below the Tuft, under precisely similar circumstances, seldom contain lead ore, except in small quantities. In the Alston Moor district the Tuft forms a line of separation, so marked as to lead to the conviction that the difference is due to lead or substances from which it is derived, existing less plentifully in the lower strata. This difference in the metalliferous character of the upper and lower parts of the Mountain Limestone does not seem to be restricted to the North of England. Sir H. De la Beche observes: "Taken as a whole, the upper part of the Mountain Limestone series is the most metalliferous, and in it certain beds appear more favourable for the occurrence of the ores of leads than others. This seems to hold equally well whether the sulphide of lead be found in fissures traversing all

the rocks, or in the joints and cavernous places in the limestone series."*

We have seen, that the conditions connected with the productive portion of Rampgill vein differ from those connected with the unproductive portion, in this important particular, that they would promote a circulation of water, in a longitudinal direction, *to* and *in* the vein: and have also shown, that water flowing in the interior of the earth, must contain in solution particles of the rocks through which it had percolated, as well as other substances derived from the atmosphere and the surface of the earth. We have stated in the preceding paragraph, as a law of experience, that the rocks forming the sides of the veins have exerted an important influence upon the deposition of lead ore. An investigation of the conditions which have promoted, as well as those which have prevented the deposition of lead ore, may be advantageously confined, in the first instance, to the veins in the upper part of the Mountain Limestone. It is in these beds that the most striking contrasts of effects are produced, and it has been well observed, that "in attempting to explain any class of phenomena, it would be well to begin with the distinct and end with the obscure."†

In the second chapter of this book, it was laid down provisionally, that a circulation of fluids is a law of causation essential to the deposition of lead ore; and in the third, it has been attempted to prove, that the percolation and circulation of water below the earth's surface are regulated generally by *five laws*. If these general propositions be correct, it follows, that a connexion must exist, between the laws regulating the percolation and circulation of water in the open spaces of the veins, and the deposition of lead ore.

* 'Geological Observer,' p. 783. † Dr. Fleming.

To a general observer, the metallic deposits seem to be very irregularly distributed in patches over the whole district of Alston Moor. It has evidently formed no plan of Nature to fill up any of the veins with lead ore throughout their whole extent, while, it must be readily admitted, by all who have considered the subject attentively, that by the co-ordination of those laws, which have really regulated the distribution of the ores in veins, the apparently discordant phenomena connected with them will be cleared up, and the whole reduced to orderly arrangement. Lord Bacon observes: "Vaga enim experientia, et se tantum sequens mera palpatio est, et homines potius stupefacit, quam informat."* And in another place of the same book: "At contra, verus experientiæ ordo primo lumen accendit, deinde per lumen iter demonstrat, incipiendo ab experientia ordinata et digesta, et minime præpostera aut erratica." † It is the general law, or theory which sets up the light directing the inquirer through the mazes of experience, while by its co-ordination, experience must ever supply a verification of the general law.

In order to prosecute this inquiry, it is necessary to separate the district of Alston Moor into portions, in which each vein may have been subjected to similar conditions of mineralization, and make the boundaries of these portions conform to the watershed of the mountains, the powerful cross veins, or some other equally distinctive marks, including as much as possible groups of the metalliferous veins. It has long been known, that veins in the same district and situated near each other are frequently filled with the same kinds of minerals. Pliny observes of silver veins: "Ubicumque una inventa vena est, non procul invenitur alia. Hoc quidem et in omni fere materia: unde metallia Græci videntur dixisse."‡ And Mr. Taylor "has observed lines

* 'Novum Organum,' Lib. i., Ap. 100.

† Ap. 82. ‡ 'Naturalis Historia,' 33, 6, 31.

of greater productiveness ranging nearly north and south across the bearing of the veins." The district of Alston Moor furnishes no general exception to these empirical laws.

Keeping what we have just stated in view, we shall endeavour to divide the district under consideration in as orderly a manner as possible, and commence with the examination of a portion of the Nenthead mines, in the south-east part of the Alston Manor, lying near the boundaries between the counties of Cumberland and Durham. The portion enclosed by this county boundary, on the east and south, includes the Middle Cleugh veins, on the east side of Handsome Mea great cross vein, two or three east portions of this latter cross vein, and another cross vein intersecting the east and west veins in the centre of the ground.

In this plot of ground, the conditions connected with the percolation and circulation of fluids are somewhat opposite. The surface rises gently for some distance on the east side of Long Cleugh Burn, forming a smooth surface of comparatively broad extent, anciently called Handsome Mea.* According to the *second law*, this gentle inclination is favourable to the percolation of water below the surface. Near the east boundary the hill rises more rapidly to the summit, which by the *first and second laws* is unfavourably situated for the free percolation of fluids below the surface. The inclination of the strata is in a north-east direction, or towards the valley; and by the *third law*, is lying in a position favourable to a free circulation near the surface. Handsome Mea great cross vein throws down the strata not less than eighty feet on the east side, or the side next the water-shed of the mountain, which, according to the *fifth law*, is unfavourable to a free circulation of fluids, especially

* "And richly clad in thy fair golden fleece,
Doo'st hold the first house of heav'n's spacious *meese*."
Sylv. Dubart, 1. iv. *See* Wright's Dictionary.

at great depths below the surface. The conditions connected with the inclinations of the beds and the throws of the veins, as affecting the circulation of fluids, are more particularly shown upon Plate VIII.

In this ground, the principal ore-producing stratum, the Great Limestone, is placed at a considerable depth below the surface, and by the *first and fifth laws*, in a position very unfavourable to the free percolation and circulation of fluids, especially near the east side of Handsome Mea cross vein, in which the douky clay, and the impervious strata of plate thrown up on the west cheek would prevent a circulation in all the veins in a longitudinal direction. If, therefore, a connexion exist between the deposition of lead ore, and a circulation of fluids in the open spaces of the veins, none ought to be found in the veins in this locality, as has indeed been proved to be the case, since scarcely the smallest particle of ore has been seen in any of them, in the ground extending one hundred fathoms on the east side of Handsome Mea cross vein,—east and west, north and south veins, being alike characterized by the total absence of this substance.

By the rise of the strata to the east on the line of Middle Cleugh second sun vein, the upper part of the Great Limestone on the east side of the cross vein, *a a*, is level with the lower part of the same stratum on the west side of Handsome Mea cross vein. As the Great Limestone rises into this position, lead ore is deposited in the Second sun vein, so sparsely, however, that hitherto it has not defrayed the cost of extraction. The small quantity, found in this east and west vein, is probably due to the veins and leads which intersect and place it under the influence of the *fourth law*. I am not aware, that any ore was found in the cross vein *a a*, at its intersection with the east and west vein.

Under Handsome Mea, where (as pointed out) the conditions

are favourable to the percolation and circulation of fluids near the surface, lead ore has been deposited in the east and west veins in the upper stratum, comprising the Slate Sills, Firestone, and Little Limestone, and even as low as the High Coal Sill, which, by the dislocation of Handsome Mea cross vein, is placed opposite the Great Limestone in the thrown-up or west cheek. It occurs so low in the Second sun vein only, and principally where it is intersected by weak quarter point veins and leads, or where the circulation to the vein has been promoted by the fourth law.

About 120 fathoms from the county boundary, Long Cleugh vein exists only as weak leads, that in all probability combine with the Second sun vein a little further to the east. The inclination of the beds is unfavourable to the circulation of fluids in the weak portions of the former to the latter vein; and where these intersections take place no lead ore has been deposited in Middle Cleugh second sun vein. Lead ore has, however, been extracted in considerable quantities from Long Cleugh vein in the Firestone stratum, at least, at a point near the cross vein *a a*, and is probably due to the fluids circulating from the east in the detached portions of the vein. From the point of intersection of Long Cleugh vein with the Second sun vein, to the east boundary, the percolation of fluids is regulated by the *first and second laws*, and the quantity in circulation must have been small. Here also the correspondence between the conditions of circulation and deposition of lead ore is perfect; for, notwithstanding the considerable width and throw of Middle Cleugh second sun vein, lead ore has not been found deposited in it, in quantities sufficient to defray the cost of mining operations.

On the south side of Long Cleugh vein, an east and west vein remains unproved; at the surface it is apparently a weak vein.

From what has been stated respecting the mineralization of veins in this locality no hope can reasonably be entertained that lead ore will be found deposited in it so low as the Great Limestone stratum. If by future trials ore is found it must be in the Slate Sills, Firestone and Little Limestone. Should the vein prove a wide one, and be subjected to the influence of the *fourth law*, it is barely possible that the deposition of lead ore may be effected as low as the High Coal Sill.

After a careful inspection of the general map, and the sections connected with this portion of mining-ground, the attentive reader cannot fail of being struck with the exact correspondence between the laws regulating the descent and circulation of fluids and the deposits of lead ore in the veins. In the Great Limestone stratum—the most plumbiferous in the district of Alston Moor—lead ore is almost entirely absent from all the veins: but then, as we have shown, this stratum is lying in a position unfavourable to the *action* of ore-depositing fluids, while in the higher strata of sandstones, which are lying in a position more favourable to a circulation, comparatively rich deposits of ore have been lodged in the open spaces of the east and west veins. Most of the veins in the Great Limestone have recently been proved, and the result of these trials corresponds exactly with the conclusions based on the principle of circulation,—conclusions arrived at before the trials were commenced.

Further west, on the line of the same east and west veins, and in ground included by Handsome Mea cross vein on the east and Carrs vein on the west, the conditions for promoting a circulation of fluids vary considerably. It will be observed upon the general map, that the circulation over the surface in this portion of the district is nearly at right angles to the direction of the east and west veins, or a direction right across the head of the vale of the Nent. The surface has a gentle inclination in

the ground traversed by the east and west veins, but rises rapidly near the south boundary. The position and inclination of the beds vary considerably, as shown upon the section No. 2, Plate VII., made from measurements taken on the line of Long Cleugh vein. The beds also rise southward in the direction of the cross veins—a general rise to the anticlinal axis, which is not affected by the dislocations of the powerful cross veins.

The position and direction of Carrs and Small Cleugh cross veins, would promote a circulation from Middle Cleugh east and west veins to the outcropping of the Great Limestone stratum—a circulation, which would also be promoted by the inclination of the beds. In this respect the functions these cross veins perform contrast strikingly with that of Handsome Mea cross vein, which, as already shown, proves a barrier to a free circulation in all the ground situated on the east side. In the ground under consideration all the east and west veins are straight and weak, except Middle Cleugh second sun vein, which is the only one that contained a very rich deposit of ore in the Great Limestone. This deposit took place where the strata are most elevated near Handsome Mea and Small Cleugh cross veins, and extended about sixty fathoms on the west side of the latter vein. It is evident that fluids would enter first the more elevated portion of the stratum, and flow from thence in the open spaces of the vein to the west. In this case it might even be supposed that metallic particles were first thrown down, and that the lighter, or non-metalliferous, were carried further west to be deposited near Carrs vein, which, by its throw and douky character, would prevent further free circulation westward at this depth. The deposits of ore in the other east and west veins have been very poor in the Great Limestone, except in a few places, where a circulation would be promoted by the *fourth law*. Elliot's string, lying on the south side of Middle Cleugh

second sun vein, might be expected to contain ore deposits of a similar kind; it is, however, a *very* straight vein, containing little space either for ore deposits or any other vein minerals. In this vein, small quantities of ore were formerly produced, but only in the elevated portion of the Great Limestone near Handsome Mea cross vein.

In this ground the Firestone stratum is lying at no great depth below the surface, in a position favourable to the percolation and circulation of fluids in the east and west veins. In this stratum, however, Middle Cleugh second sun vein and Long Cleugh vein have both been proved to contain no lead ore. The matter contained in these veins is often broken and loose, mixed with a sandy sediment or residue, and may be considered as an indication, that after the deposition of the ore was effected, it has been removed by some change in the composition of the circulating fluids.* Near Handsome Mea cross vein, Middle Cleugh second sun vein contained some lead ore in the Girdle beds, which are situated a little below the Firestone. In this case, the lead ore might be protected from the erosive action of the fluids, circulating in the more porous part of the vein in the harder stratum above, by the platy or shaly matter which generally surrounds vein-stuff in these beds. Although the Middle Cleugh veins are scattered and weak, some lead ore has been produced from them in the Firestone stratum. The ore is often found loose and detached from the rock, upon which it had originally been deposited, and not unfrequently partially changed into a carbonate of lead. The old works, made in these veins upwards of a hundred years ago, were lately opened out and partially re-worked. I recollect in one place, a vein had been worked some

* Pliny supposes the contents of veins to be subject to decomposition.
"Ut plane intelligatur nihil aliud chrysocolla quam vena putris."
Nat. Hist. lib. 33, 5, 26.

ten or twelve feet above the roof of an opening drift, and not more than six or eight inches wide, lead ore had been found mixed with a loose sediment, the result of decomposition after the deposition of the ore had been effected. The contents of the vein had been abstracted by the miners by means of iron prongs. Some pieces of ory vein-stuff, which they had been unable to bring down, remained suspended in the open space of the vein, attesting their mode of operation.

Setting aside, for the present, the consideration of the conditions connected with deposits of lead ore in the cross veins, we shall endeavour to point out those connected with the Middle Cleugh group of east and west veins, on the west side of Carrs vein.

We have already attempted to show why these east and west veins are stronger and wider on the west than on the east side of Carrs vein;* and the elevated position of the strata on the west side of this vein is shown upon the series of sections, Plate VII. It will also be observed that in the direction of these east and west veins westward, the strata gradually sink into a lower position. The Firestone may be considered as the highest stratum of hard rock; the Great Limestone is therefore situated at a moderate depth below the surface. The veins traverse the mountain side, at a considerable distance from its water shed, and in accordance with the first law, a large quantity of water must flow over and sink below the surface. The surface, thickly covered with alluvium, inclines gently, which, by the *second law*, is favourable to the percolation of water below the earth's surface; while, by the inclination of the strata, this portion of mining ground is equally favourable to a circulation in the direction of the veins, from the east to the west. All these

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* See Book I., Ch. iv.

favourable conditions prevail until the veins begin to pass under the summit of Middle Fell.

The connexion between these conditions regulating the percolation and circulation of fluids, and the deposition of lead ore, is very striking. All of them have contained very rich deposits of lead ore in all the hard strata, but particularly so where they are most elevated near to Carrs vein, and where they are subjected to the influences of the fourth law by intersections with Cowslitts and Cowhill weak cross veins. As these east and west veins pass under the summit of Middle Fell, they are subjected almost entirely to the *first law* regulating the descent of fluids. Here, the agreement between the laws effecting the percolation of water and the deposition of lead ore, is no less striking; for the veins cease to contain this substance, first in the lower part of the Great Limestone, and then in its upper part, while, in the strata lying nearer to the surface, the quantity of ore deposited in them is much diminished, and in many places is too small to defray the cost of extraction. Under such conditions, the most metalliferous limestone is unproductive of lead ore, while near to Carrs vein, considerable quantities have been deposited even in the plate beds.

In the two portions of ground we have had under consideration, it is evident that the mineralization of the cross veins with metallic substances should be connected in the same way, to the laws of percolation and circulation of fluids as the east and west veins. It has already been pointed out, in the third chapter of this book, that their hade is less favourable to the formation of open spaces in the upper strata than that of the east and west veins; but whether this is the only cause that has prevented the deposition of lead ore in these cross veins in such strata, is perhaps somewhat doubtful. It may however be stated as a law of experience, that up to the present time, no

important deposits of ore have been found in them in such strata, and that the trifling exceptions only occur, where the conditions approximate to those of the east and west veins. Our remarks are therefore restricted to deposits of lead ore found in them in the Great Limestone.

The east portions of Handsome Mea cross vein are generally wide and sparry when both sides of the veins are formed by the Great Limestone; but, as already pointed out, by the throw of the west portion of the vein this stratum is placed in a position very unfavourable to the percolation and circulation of fluids The connexion between these conditions and the non-deposition of lead ore is perfect: notwithstanding that extensive trials have been made, *no* lead ore has as yet been found in them.

Upon inspection of Section No. 2, Plate VII., the careful reader will note, not only the very different position of the Great Limestone, but likewise, how well the inclination of the beds is adapted to promote a free circulation from the west cheek of this powerful vein. It should however be remembered, that on account of the throw of this west portion of the vein exceeding the thickness of the Great Limestone, this stratum is placed in the thrown up cheek, opposite beds of plate, and, the Coal Sills. Under such conditions, after the formation of the vein, spaces could not long remain open, but would soon be filled with broken strata and pounded or decomposed shale, and, in consequence, no deposition of lead ore could take place. On the north side of the Middle Cleugh veins, where the east portions fall into and combine with the west portion, the throw of the latter is so much diminished that its cheeks in the Great Limestone are not thrown past each other. (See Fig. 2, Plate XVI.) In this ground of about 55 or 60 fathoms in length, or from *a* to *b* upon the same Fig. 2, a large quantity of ore was found

deposited, and has lately been abstracted. It is evident, therefore, that lead ore found in Handsome Mea great cross vein, is the result of the same laws of causation as effected its deposition in east and west veins; the essential antecedents in each case being conditions favourable to the formation of open spaces in hard rock, and those necessary to the circulation of fluids. Lead ore is absent where one or both of these antecedents are wanting; as in the east portions of this cross vein where extensive spaces have been formed, but through which fluids circulated sluggishly or not at all; or as in the west portion, where the conditions for promoting a circulation exist, but where no open spaces have been formed: in the former instance the veins are filled with carbonates of lime and iron or quartz, in the latter chiefly with broken strata and douk.

No cross vein, hitherto discovered in Alston Moor, has contained such rich deposits of lead ore as Small Cleugh cross vein, in the ground northward from the Middle Cleugh veins. Like Handsome Mea cross vein, the ore is only found in it where its opposite sides, or cheeks, are both formed of Great Limestone. Where these rich deposits occur, the vein is situated in a trough or hollow, occasioned by the strata inclining from Handsome Mea cross vein, and also from Carrs vein, towards it. Consequently the fluids would circulate to this vein through the numerous small leads and strings connected with the east and west veins. Upon a careful inspection of the general map, and Plate XVII., it seems highly probable, that in the ground lying between Handsome Mea and Carrs cross veins, Small Cleugh cross vein has formed the main drain in which the fluids were collected to circulate to the surface—a circulation which would be promoted, as previously observed, by the general inclination of the beds to the north.

Small quantities of ore have been produced from the strings

and flats of the thrown-down cheek of this vein; in this respect proving an exception to the other cross veins, which have very seldom contained ore in such a position: but from the general view we have taken of the functions of the vein in promoting a circulation in a longitudinal direction to the surface, the conditions do not appear very unfavourable to the deposition of lead ore. The deposits have, however, been very poor, and are only found where the vein is much subjected to the *fourth law*. As this vein approaches the thrown-down cheek of Carrs vein, it ceases to contain much lead ore, being chiefly filled with carbonates of lime and iron.

On the south side of Long Cleugh vein, a combination of Handsome Mea and Small Cleugh cross veins takes place. No lead ore has been found at the point where this combination occurs; but in the west cheek, where the Great Limestone is much elevated, and lying at a considerable inclination, some ore has been deposited in the west strings. The trials for proof of these veins have not as yet been extended further south than a series of east and west leads which intersect the cross veins about 50 or 60 fathoms on the south side of Long Cleugh vein: it is probable, however, that the deposition of lead ore in them has been prevented by the *first law* regulating the percolation of fluids. Indeed it is questionable whether these cross veins would have contained any ore in the locality of Long Cleugh vein, but for the numerous intersecting strings and leads which bring them in a peculiar manner under the influence of the *fourth law*.

Carrs vein, on the south side of Long Cleugh vein, contains richer deposits of lead ore than have as yet been found in the Small Cleugh cross veins, south of the same east and west vein. The ore was found chiefly in the west or thrown-up cheek, and the largest quantity, at the point where a combination takes place, at a very acute angle between it and Cowslitts cross vein.

Hence the west cheek is much fractured with numerous cross strings as well as east and west leads, as may be observed upon the map. Like Small Cleugh cross veins, in the ground further south, its mineralization with metallic matter has probably been prevented by the *first law* regulating the descent of fluids. In this unproved ground the vein probably exists in two portions, each of which throws the cheeks of the Great Limestone nearly past each other, a condition unfavourable to the formation of open spaces in the veins. Similar conditions also prevail on the north side of the Middle Cleugh second sun vein, where the vein is not ramified, and its throw places the bottom of the Great Limestone in the thrown-up cheek opposite the plate bed below the Coal Sills. In consequence, the vein is filled with douk.

Cowhill cross vein has also contained a very rich deposit of lead ore in parallel ground, and of about equal extent to that in Carrs vein. The open spaces in which the ore was lodged and in connexion with sparry substances, nearly filled up, are represented upon Plate XI. It was found lodged chiefly between *a* and *b*, but in both portions of the vein. The fluids which circulated in this vein would descend chiefly through the numerous east and west leads and two or three weak quarter point veins.

There is one circumstance, too remarkable to be passed over, connected with ore deposits in these cross veins—namely, that where proper spaces have been formed in the vein itself, and the other conditions for promoting a percolation and circulation of fluids are favourable, the deposition of lead ore has been effected most abundantly in ground opposite to a point where an east and west vein is broken up. In the instance of Cowhill cross vein, Wellhope knot vein breaks up in the neighbourhood of the Black Ashgill cross veins; it is, however, highly probable that portions not wider than a boot lace extend to Cowhill cross vein; and it may be, pass through it and exert an influence upon the mineralization of Carrs vein.

From the fact of the ore deposits in the cross veins being so much influenced by the leads connected with the east and west veins, it may be inferred that the mineralization of the former with lead ore has taken place either contemporaneously with the latter, or subsequently. This inference derives some confirmation from the fact, that on the north side of Long Cleugh vein, Cowhill cross vein is much straighter and weaker than where the ore deposit occurs on the south side. It may be pointed out that the throws of these two veins are affected at their intersection in an equal degree, the one losing and the other gaining about seven feet. It seems therefore highly probable, that the open spaces in Cowhill cross vein, on the south side of Long Cleugh vein, were formed after its mineralization with carbonate of iron, and that the deposition of this substance took place under conditions different from those which subsequently effected the rich deposits of ore in the Middle Cleugh veins.* It would also appear that, on the north side of Long Cleugh vein, and at the time of the formation of the open spaces in the east and west veins now filled with lead ore, Cowhill cross vein was not subjected to the same changes, or subjected in a less degree, for it still contains the original deposit of carbonates of iron and lime, and has not been subjected to the ore-depositing influences that enriched the east and west veins.

In the portion of the Nenthead district we have had under consideration, several extensive flats have been formed, and their cavernous parts enriched with much lead ore. These ore

* While working the rich ground in Cowhill cross vein, the miners holed into a large cavern, the lower part of which was filled with vein stuff, chiefly composed of carbonates of lime and iron, all of which was fractured and broken in a manner similar to the lumps of veinstone left in mines as refuse. When the miners entered the cavern, they felt assured that they had holed into some old works. It is remarkable that none of the fractured vein stuff contained the least particle of lead ore.

deposits occur only where the Great Limestone is much elevated above its regular position, or inclines considerably from the cross veins. The conditions connected with Handsome Mea or Small Cleugh flats, the most extensive ever found in Nenthead, or even in Alston Moor, are represented upon the large map and the sections Plates XIII. and XIV. These illustrations need no further explanation; for the attentive reader cannot fail being impressed with their adaptation to promote a circulation of fluids. We have already pointed out the large quantity of limestone which has undergone decomposition and change where these rich ore deposits in flats occur. Such changes have taken place, and similar open spaces (but less extensive) have been formed in other parts of the district, where no lead ore is deposited in them. Some of these will be noticed, but it can invariably be shown that in the latter case conditions prevail which are unfavourable to the percolation and circulation of fluids.

Upon the general map the comparative richness of the productive ground is distinguished by the colours blue, red, and yellow. The whole amount of variation can scarcely, however, be represented upon any map to its full extent. The conditions connected with the circulation of fluids suffer the most abrupt changes by the throws of the powerful cross veins. A careful inspection and study of the portion of the map representing the district we have had under consideration, will lead to the conviction that the deposition of lead ore is equally dependent on those changes. This variation, corresponding as it does so generally with the *fifth law* regulating the percolation and circulation of fluids below the earth's surface, furnishes a striking proof that the former is a sequence of the latter, or connected with it by some law of causation.

Again, looking at the subject from a still more general point of view, it becomes evident that the percolation and circulation

of fluids in the interior of the mountains stretching eastward from Burnhope Seat to Kilhope Law, must be promoted by the erosion of the valleys of the Tyne, the Nent, and the Allens on the north, and the tributaries of the Tees and Wear on the south. At the head of these valleys, a free circulation must be promoted to greater depths than can take place at the junctions between the more elevated east and west range of mountains and those which separate these valleys from each other. Hence it follows, that if the deposition of lead ore is dependent upon a circulation of fluids, all veins traversing the east and west range should contain richer deposits at the head of the valleys than at the points where the two opposite ranges intersect or unite with each other.

We have already shown that in the veins situated at the head of the Nent, this connexion exists; that, subject to modifying circumstances, the veins have contained the richest deposits at the head of the Nent river; and that, as they approach the ranges of mountains, situated on each side of the valley of the Nent, they cease to contain lead ore even in the most metalliferous stratum of limestone rock. This exact correspondence of facts to theory in its particular and most general aspects, tends to establish the doctrine of a circulation of fluids as a law of causation essential to the deposition of lead ore, and as a truth of the deepest importance to practical mining.

For the present, leaving the inquiry respecting the Middle Cleugh veins, at the point on the west side of the Nent valley, where they cease to contain lead ore in the Great Limestone, we shall endeavour to trace a connection between the conditions effecting the percolation and circulation of fluids in the veins lying further north, and on the east side of the Nent river. This portion of the district comprises Hangingshaw east and west veins, Rampgill and Scaleburn veins, and their continuation as the principal veins in the Coal Cleugh district.

CHAPTER VII.

OF THE CONNEXION BETWEEN THE LAWS OF HYDROUS AGENCY AND THE DEPOSITION OF LEAD ORE IN VEINS ON THE EAST SIDE OF THE NENT RIVER.

BY referring to the general map, the reader will perceive that on the east and west range of mountains between Long Cleugh Head and Kilhope Law the line denoting the heaven's water division bends to the north in the form of a triangle. The anticlinal axis also bends in the same direction, but the extreme north point of the curve scarcely extends further than the outcropping of the Little Limestone or Coal Sills in the upper part of the Kilhope valley; in consequence, the strata above these continue to rise from the Coal Cleugh and Alston Moor Districts, until they basset on the contrary side of the mountain.

This circumstance necessarily modifies the effect of the *first law* regulating the descent of fluids, since it is evident, that water which percolates the cross veins and quarter point fissures on the south side of the mountain, must be carried by the inclination of the beds, and issue as springs on the north side, either in the Alston Moor or Coal Cleugh district. The whole of the ground comprehended between Rampgill cross vein and Coal Cleugh east cross vein is traversed by veins of this character, as may be seen upon an inspection of the map and plano-section,

Plate IX., where these veins are carefully represented, especially upon the latter. It will be observed that the quarter point fissures run between Kilhope and the Alston Moor district, while the veins and strings running in a north and south direction intersect the east and west veins in the Coal Cleugh district. It is probable, that more of these intersecting veins and fissures exist than are denoted upon the maps. We are therefore justified in concluding, that a considerable quantity of fluids must have circulated in strata situated at great depths below the summit of this mountain. This circulation would also be promoted by a broad surface on the Kilhope side being comparatively smooth and unbroken with glens, and also, by its being thickly covered with alluvium, which, like a sponge, would hold the water and allow it slowly to settle into the fissures traversing the rocks.

On the east side of a tributary of West Allen river, called Bridge Cleugh, the laws regulating the percolation of fluids are not subjected to the modifying conditions we have just described. The range of mountains separating the two Allens joins the east and west range, and at the point of junction the latter takes a direction nearly south, separating the vale of Kilhope from the upper part of East Allendale. Here, in a plot of ground of considerable extent, surrounding Kilhope Law, the conditions are unfavourable for promoting the free descent of fluids into strata situated at a great depth from the surface. Nor does it appear that their unfavourable character is much modified by the *fourth law.*

If the percolation and circulation of fluids are essential to the deposition of lead ore, it is manifest that the conditions just noticed must be accompanied with corresponding variations in the quantity of lead ore deposited in Rampgill vein, and in its continuation as High Coal Cleugh vein. We might reasonably

expect that lead ore would be deposited, even where the position of the vein is near the watershed of the mountain, or one generally unfavourable to the deposition of lead ore at great depths below the surface, and such has really been the case. In the whole extent of ground comprehended on the plano-section between *c* and *d* the vein has contained very large quantities of lead ore in all the hard strata from near the surface to the bottom of the Quarry hazle; the richest portions being situated near the thrown-up cheek of the cross veins, where the strata have generally the greatest amount of inclination, which promotes a longitudinal circulation in the vein. In the short length of ground between the two powerful Coal Cleugh cross veins, this east and west vein contained no lead ore in the Great Limestone stratum. This accords with the position of the strata, which is very unfavourable to a circulation in a longitudinal direction, and according to the theory, unfavourable to the deposition of lead ore.

That the deposition of lead ore, in such large quantities in Rampgill and Coal Cleugh veins, is due to a circulation of fluids from the opposite side of the mountain, receives confirmation from the fact, that the other portion of the vein, situated below the summit of the mountain which separates the vales of the two Allens, and where, we have shown, the modifying causes do not exist, the ore deposits have been poor, and directly below the summit of the hill have not been effected so low as the Great Limestone stratum; notwithstanding the vein is farther removed from the summit of the east and west range of mountains. To this latter circumstance, it is probably due, that a sufficiency of fluids has descended to effect the deposition of lead ore in the strata above the Great Limestone.

No large quantity of lead ore has, hitherto, been raised from any of the Coal Cleugh cross veins. The throws of the two most

powerful ones place the cheeks of the Great Limestone stratum opposite beds of plate and thin sandstones. Like the Nenthead cross veins under similar circumstances, they contain little else than douk. The throw of the Pump-sump cross vein is not more than 36 feet, and some ore has been produced from it. The places most likely to contain ore deposits in these cross veins are the strings lying off the principal portions of the veins in the thrown-up cheeks, and where conditions exist most favourable for promoting a circulation of fluids.

In connexion with the Coal Cleugh veins, extensive flats have been formed which have been enriched with much lead ore. These flats are chiefly found in the upper flat post, and the richest deposits occur near the cross veins, and in all cases they are accompanied with numerous intersecting leads or strings connected with the east and west as well as the north and south veins.

The deposition of lead ore, in the weak east and west veins on the south side of Rampgill vein, is due to conditions promotive of the descent and circulation of fluids from the surface, the locality being peculiarly placed under the influence of the *fourth law*, or law of intersections. At the intersection of Rampgill second sun vein and Rampgill cross vein the Great Limestone has undergone much decomposition and change; and from some fifteen to twenty fathoms in length of the former vein, on the west side of the latter, an exceedingly large quantity of lead ore has been extracted. Large quantities of lead ore have also been procured from Rampgill cross vein and the flats formed on each side; but northward from Rampgill sun vein to Scaleburn vein the ore deposits in it were very poor. About 100 fathoms south of its intersection with Rampgill second sun vein, this cross vein ceased to produce lead ore, and in a long tract of ground extending through the summit of the hill no trial of it has been made;

and if the law of circulation is admitted to be essential to the deposition of lead ore, then it seems probable that none will be found in this unproved portion of the vein, unless effected by a circulation from the Kilhope side of the mountain, which seems unlikely, its course being too near the summit of the hill separating the valleys of Kilhope and Welhope, and in accordance with the *first law*, a free circulation of fluids could scarcely be effected in this district so low as the Great limestone stratum.

Patterdale cross vein is situated west from Rampgill cross vein, and traverses the mountain in a parallel direction. The conditions connected with the percolation and circulation of fluids are also very similar. Extensive trials have been made in this vein, but with the exception of a short length of ground between Rampgill and Rampgill sun veins, where it is placed in a peculiar manner under the influence of the *fourth law*, no lead ore has yet been found in it. Hangingshaw east end veins have also been found quite unproductive of lead ore in the Great Limestone stratum. The situation of these veins on the thrown-down cheek of Handsome Mea great cross vein is one very unfavourable to a free circulation of fluids. Some lead ore was procured from one of these east and west veins in the upper strata of Firestone and Little Limestone, but the length of productive ground was very limited.

The fluids percolating the Kilhope side of the mountain, and flowing in the weak fissures to the north, would gradually diminish in quantity, first in the strata lying nearest the surface; for like a semi-fluid mass poured upon a level surface they would become diffused as they settled to lower levels, and this more particularly in the Great Limestone, which is placed horizontally in a position most nearly corresponding to the bottom of the valleys, and consequently, may be considered as the

lowest draining stratum. In the upper strata, the fluids would be drawn off by entering channels communicating with the surface, from which they would issue as springs.

The same quarter point fissures, which intersect Rampgill vein, have also brought Scaleburn vein under the productive influences of the *fourth law*. With the exception of the modification pointed out in the preceding paragraph, it has been subjected to the same conditions of circulation as Rampgill vein, for these fissures have evidently been the channels in which the fluids circulated to the vein. The deposits of lead ore, in Scaleburn vein, occur chiefly in strata comprehended inclusively between the Pattinson and the Tuft; and similar to Rampgill vein, the deposition of lead ore has been effected through the summit of the hill separating the valleys of the Nent and West Allen. In the Firestone and Slate Sills the vein contains very little lead ore, in the Alston Moor side of the boundary. These are the strata in which a circulation would be dependent upon the percolation of fluids in the immediate locality, under the preventive influences of the *first law*, and also modified, unfavourably to its permeation, by the *second*. In the Coal Cleugh district the vein, although not rich near the boundary, has contained lead ore in the upper strata which has well repaid the cost of extraction; and it is a confirmation of the laws of hydrous agency, that in this district, the surface is more favourably situated for the percolation of water flowing from the heaven's-water division separating the counties of Northumberland and Durham. The deposits of lead ore in Scaleburn vein were generally less rich and more irregularly distributed than in Rampgill vein. In some places, these ore deposits are so poor, that considerable portions of the vein remain unworked. Like Rampgill vein, on the west side of Rampgill and Scaleburn cross vein, it gradually ceases to contain lead ore in the Great Lime-

stone, as this stratum sinks below its general position, approaching the thrown-down cheeks of the powerful Nenthead cross veins.

Throughout the whole extent of Scaleburn vein in both the Coal Cleugh and Nenthead districts, the Great Limestone has suffered much decomposition and change, and extensive flats occur, particularly at the various points, where it should be intersected by the quarter point fissures and cross leads that pass through Rampgill and High Coal Cleugh vein. Large quantities of lead ore have been produced at various periods from these flats, the richest of which probably occurred between the Pumpsump cross vein, and Coal Cleugh west cross vein.

On the north side of Scaleburn vein, a rich deposit of lead ore was found in Rampgill and Scaleburn cross vein, at a point much intersected with leads running in various directions. The Great Limestone is moderately elevated above its position on the thrown-down cheek of Carrs vein, and where it is traversed by this vein, its considerable inclination to the north, and also to the west, would be promotive of a circulation of fluids. Northward from these intersections, only a small quantity of lead ore is found in it, which has been partially worked to within some forty fathoms of Broomsberry cross vein.

The ground west of Rampgill and Scaleburn cross vein, and lying between Rampgill and Guddamgill east and west veins, is favourably situated for promoting the descent of fluids under the *first law*: but on account of the great throw of Carrs vein, in accordance with the *fifth law*, the conditions are very unfavourable to their circulation.

An intimate connexion exists between these unfavourable conditions for promoting a circulation, and the non-deposition of lead ore. On the north side of Scaleburn vein numerous trials have been made in these cross veins, but very little lead

ore has been produced from them, the whole amounting to some four or five hundred bings. This small quantity was found in Fairhill cross veins, and close to the north side of Scaleburn north vein. It will be observed on the plano-section Plate IX., that the Great Limestone is elevated considerably above its general position on the thrown-down cheek of Handsome Mea great cross vein. On the north side of Gillgill Burn, as these veins approach Carrs vein, they cease to contain even the smallest quantity of lead ore. The conditions of position as verifying the *fifth law* are also shown upon Plate XVIII.

In the ground situated between Gillgill and Guddamgill Burns, and on the east side of the Nenthead cross veins, the supply of fluids has probably been restricted to their percolation from the surface; and in accordance with the *first law*, under the summit of the mountain and under the lateral ridge separating Gillgill and Guddamgill Burns, the quantity circulating must have been small. The strata in this tract of ground are not much broken by veins of any description, the only one of importance being Guddamgill vein.

This vein is of a similar character to Scaleburn and Rampgill veins; it is wide, and contains much vein mineral. In the direction of its course eastward, the strata, after being thrown down by Carrs vein, do not rise so rapidly into an elevated position as they do on the line of the east and west veins just named, in which, as previously pointed out, no lead ore of importance has been deposited in the Great Limestone when depressed below a certain level. It is owing to a similar reason, and also to its proximity to the lateral ridge, that a free percolation and circulation have not been effected in Guddamgill vein, and consequently no rich deposits of ore lodged in the Great Limestone west of its intersection with the Black Jack vein. Where this intersection occurs, the vein contained much ore in all the strata,

with the exception of the Firestone, which lies close to the surface. It is to be observed, that where this deposit occurs, all the fluids, collected in a long tract of ground stretching to the east boundary, pass over the vein, and percolate under the favourable influences of the *fourth law.*

It is not a little remarkable, that Guddamgill vein, so poor generally in deposits of lead ore, should contain richer deposits of sulphide of zinc than any other vein in Alston Moor. It is found plentifully deposited in all the strata between the Pattinson and the Tuft; but the richest deposits occur in the two limestone strata. Generally in the Nenthead mining district, at the bottom of a stratum, the east and west veins are filled with a great quantity of sulphide of zinc, which gradually becomes less in the upper part where the veins contain the most lead ore. It is also found plentifully deposited in many veins where the strata are placed in a somewhat unfavourable position for the deposition of lead ore; but when the strata are placed in a very unfavourable position, it is never plentifully deposited, although it may occur sparsely mixed with the carbonates of lime and iron. From these facts, one might almost conclude, that a less amount of circulation has effected the deposition of sulphide of zinc than lead ore, and that the presence of the former in Guddamgill vein, in such large quantities, is an indication that the circulation in the vein has not been sufficiently free to effect the deposition of the latter more valuable metal. Sir H. De la Beche observes: "In veins of mixed ores of different metals, where some of each are found disseminated through them, the relative abundance of the ores is sometimes found most materially modified at different depths, and this occasionally even to a certain extent irrespective of the kinds of rock forming the walls of the veins, though this influence requires always to be steadily borne in mind. Thus with some ores of zinc, lead, and copper, as, for

example, in the well-known Ecton mine, Staffordshire, the sulphide of zinc was found most abundant in the depth, the sulphide of copper occupied a central position, and sulphide of lead was found in the higher parts. In the Spital vein at Schemnitz, according to Mr. Warrington Smyth, where the sulphides of silver and lead are raised, though the latter is argentiferous beneath, the ores towards the higher portions of the vein are chiefly sulphides and other ores of silver, in which either lead is scarce or absent." * It may be questionable whether a difference in the freeness of a circulation is simply the only cause why, in these instances, different kinds of metallic ores are separately deposited more plentifully in one part of the vein than in another. In the Nenthead veins, however, it is evident that so far as the deposition of the ores of lead and zinc is concerned, the laws of causation in each case are very intimately connected. Speaking generally, the ores of lead occur much more plentifully in the veins of Alston Moor, and in larger and purer masses than the ores of zinc. The vertical range of zinc ore is also more limited than lead ore; scarcely any has been deposited in the strata above the Little Limestone, and so far as the veins are proved, very little of it below the Great Limestone. In the Coal Sills and Little Limestone, the oxides of iron and it are so intimately blended together, that it is almost impossible to separate them by washing processes, there being little difference in their specific gravities. In consequence of this blending together, the ore of zinc produced from such strata is rendered valueless, and cannot be smelted to profit.

In the small patch of Great Limestone, which constitutes the surface stratum on the west side of Carrs vein and south from

* 'Geological Observer,' p. 791.

Guddamgill vein, lead ore has been found in detached lumps of rider lying near the surface. The vein stuff containing much carbonate of iron, deposited in limestone strata so near the surface, must be subjected to the decomposing effects of atmospheric agency; and if the west strings of Carrs vein ever contained ribs of lead ore they have been long ago removed from their places of deposit, which are now filled with rich oxides of iron.

The next plot of ground lies to the north of Guddamgill Burn, and comprehends Brownley Hill veins and the continuation of the principal vein into Wellhope.

The quantity of fluids which flow over a great portion of this ground is modified to a considerable extent by the *Dod*, which is a peaked elevation rising above the regular summit of the mountain, and that to a considerable height. In consequence, a long tract of surface unbroken with cleughs or glens, is formed on the east side of Brownley Hill cross veins, which is favourable to the percolation of fluids. The formation of the surface on the line of Brownley Hill old vein is also not unfavourable to the percolation of fluids under the *first and third laws*, although, on account of the steepness of the hill on the south side of the vein, the conditions for promoting the descent of fluids is somewhat unfavourable under the *second*.

Brownley Hill vein is about the same magnitude as Scaleburn and Guddamgill veins. It has contained much larger quantities of lead ore than the latter, though it has been less rich than the former. On the east side of Carrs vein, the ground is very favourable to the percolation of fluids; but, by the throw of Carrs vein, the strata are placed in a position very unfavourable to their circulation, and as in the case of the veins previously noticed, no lead ore of importance has been deposited so low as the Great Limestone stratum; and, corresponding with the laws of circulation, it is not until this stratum attains a

higher position, on the east side of Guddamgill Burn cross vein, that the vein contained in it rich deposits of lead ore. From the last-mentioned cross vein, the strata rise somewhat rapidly to the east on the line of Brownley Hill vein, thus promoting a circulation similar to what has taken place in Rampgill and Scaleburn veins. Directly below the anticlinal axis, the vein ceased to contain lead ore in all the strata; but the ground so affected is comparatively short, for in Mr. Beaumont's Manor, rich deposits occurred in all the strata from the top of the Slate Sills to the bottom of the Great Limestone. The portion of the vein in which these deposits were found is situated at the head of Wellhope Burn and directly opposite to the Dod. The strata, which are said to be much fissured, rise rapidly from the south side of Wellhope vein, and continue to do so through the summit of the Dod. It is evident, that all the fluids circulating in these fissures, to the outcropping of the various strata in Wellhope Burn, must flow over or circulate in this rich portion of Wellhope vein. In the ground under the summit of the hill separating Wellhope Burn from West Allen, the percolation of fluids in large quantities would be prevented by the *first law.* Accordingly no lead ore is deposited in Wellhope head vein. Indeed in all the ground traversed by Brownley hill vein, the correspondence between the conditions of percolation and circulation of fluids, and the deposition of lead ore is close and well defined.

Brownley Hill high cross vein traverses the district in a direction nearly at right angles to the circulation of fluids, over the long tract of surface extending to the Dod; and which percolating the numerous quarter point fissures must promote their descent to great depths below the surface, under the influence of the *fourth law.* Brownley Hill sun veins, which exist on the east side of Guddamgill Burn cross vein, break up altogether before they reach these High cross veins. It is in the ground

where intersections with them should have taken place, that the richest deposits of ore were found in the cross veins. In this respect, they resemble Cowhill cross vein on the south side of Long Cleugh vein, which, as pointed out, contained the richest deposit of lead ore, where it should have been intersected with Woodmerwell or Wellhope knot vein. In their direction southward, Brownley Hill high cross veins all become exceedingly weak, and, with the exception of the Jug vein, ultimately waste away. Under such circumstances, notwithstanding the favourable locality, for the promotion of the percolation and circulation of fluids, no lead ore has hitherto been found in them.

Connected with the group of powerful veins traversing the west portion of Brownley Hill mining plot, very favourable conditions exist for promoting the percolation of fluids. This portion of the ground is also very much fissured and broken with weak veins and strings running in an east and west direction, particularly on the east side of Guddamgill Burn cross vein. The throw of Carrs vein places the Great Limestone on the east side opposite to the Four-fathoms Limestone and Nattrassgill hazle; but, on account of the denudation at the surface in Guddamgill Burn, it is lying very little below the surface. The conditions for promoting a circulation are, however, best shown by the cross section, Plate XIX., in the direction of Guddamgill Burn, where it will be perceived that in the ground between the two portions of Carrs vein, the Great Limestone is lying in a very unfavourable position for promoting the circulation of fluids. In this ground, the east cross vein has been proved to contain no lead ore.

From this east portion of Carrs vein the strata rise to the east, and at Wellgill cross vein have attained a position above the bed of the Nent river below its junction with Guddamgill Burn. And it is a remarkable exemplification of the law of circulation as being essential to the deposition of lead ore, that

below Guddamgill Burn, where the greatest amount of denudation has been effected, this vein should contain a rich deposit of lead ore. For, further south, veins of the same character, situated about the same distance from Carrs vein, and connected with which are conditions in all respects similar, excepting those relating to the circulation of fluids, are found to contain none. As a result of our investigations, we have endeavoured to establish the general empirical law, that the thrown-down cheeks of the Nenthead strong cross veins do not contain deposits of lead ore, and that all veins lying near them on that side are also barren. This exception, and that of Carrs sun veins, agree in being connected with conditions promotive of a circulation, and in consequence confirm the higher law of causation. In the same stripe of depressed strata, Wellgill cross vein in its course northward, under the sides of a steep mountain, becomes very poor, notwithstanding the many intersections promotive of a circulation under the influence of the *fourth law*. On the north side of Brownley Hill vein it ceased altogether to contain lead ore.

Guddamgill Burn cross vein contained much ore in all the ground between Guddamgill and Brownley Hill veins. On the east side of the vein, so numerous are the intersecting veins and leads, chiefly running in an east and west direction, that, at some places near the surface, the Little Limestone is, by decomposition and change, converted into a stratum of carbonate of iron. On account of the rise of the strata to the east, the fluids would flow to the upper cheek of the vein and settle from thence into the lower. The general conditions promoting their percolation and circulation are manifestly the same as those connected with Wellgill cross vein.

The plot of ground lying to the north of Brownley Hill veins, and the south side of Lovelady Shield Burn, differs from that we

have just had under consideration in not being broken into by deep glens or burns. It will also be perceived upon the map, that the heaven's-water division is less removed from the east portion of the powerful cross veins.

On the west side of Carrs vein the Great Limestone is the surface stratum, and is much broken by joints, and lying in a position very susceptible of atmospheric decomposition. If the Nentsberry Greens veins ever contained rich deposits of lead ore, which is not unlikely, it must long ago have been almost entirely removed by these agencies.

The position of the Great Limestone on the east side of Carrs vein is shown upon the section Plate XX. In this ground no lead ore has been found. The Great Limestone is tilted into a somewhat higher position by Wellgill cross vein, in which, a rich deposit of lead ore occurred at a point where the east cheek is much broken with quarter point fissures, and also, where an intersection with Nentsberry Haggs veins would have taken place had these veins not ceased to exist on the west side of Carrs vein.*

The few east and west veins found to exist on the east side of Carrs vein are all weak. On account of the ground being contiguous to the summit of the mountain a plentiful percolation of fluids would be prevented under the *first law*. None of the veins have contained lead ore except High Raise vein in the Slate Sills and Firestone, and in a short length of ground in the upper part of the Great Limestone.

In the ground between Lovelady Shield and Foreshield Burns only a small patch of Great Limestone exists on the west side of

* This section (Plate XX.), was copied from one made by the late Mr. Broadwood, and is drawn on the line of Nentsberry Haggs sun vein. The red lines represent the Old Haggs levels. The rich deposit of lead ore in Wellgill cross vein was found at the point *a*. I apprehend that Wellgill and Old Carrs cross veins will hade to each other more rapidly than drawn upon the section indeed it is probable they are one vein in the Whin.

Carrs vein. It is much broken with joints, and lying close to the surface. In accordance with the *fifth law* the throw of Carrs vein, being not less than 220 feet, places the Great Limestone stratum in a position unfavourable to a circulation of fluids in the east cross veins. Extensive trials were made, but no lead ore of importance found in them.

At Foreshield the Nent river bends to the west. In consequence, on the west side of Blaygill cross vein, a considerable tract of ground is occupied by the Great Limestone and strata above, all lying in a position more favourable to the percolation and circulation of fluids than the same series of beds on the east side of these strong cross veins.

In the ridge separating Blaygill and Foreshield Burns the conditions for promoting the percolation and circulation of fluids do not appear favourable under the *second law*, the sides of the hill having a considerable inclination. It is, however, very much fractured and broken by veins and fissures traversing it in various directions, and in consequence very much brought under the influence of the *fourth law*. The rise of the strata from the Blaygill side right through this ridge of hill would also promote a circulation of fluids from the south side to the Blaygill veins, under the *third law*.

On the west side of Blaygill cross vein, where the conditions are favourable to a free circulation of fluids, Blaygill east and west veins have all contained rich deposits of lead ore, particularly Fistas Rake vein, where it is intersected with the Sunnyside veins: but on the east side of that cross vein none of any importance. The Sunny side veins traverse the district nearly in a quarter point direction. On the south side of Fistas Rake vein, Blaygill cross vein throws the east side down only three fathoms. In this ground, extending about ninety fathoms south, the vein contained much lead ore. About thirty fathoms of ground on the

north side also produced some lead ore; the throw of the vein, however, rapidly increases until it exceeds the thickness of the Great Limestone; under this condition, as might be expected, no lead ore has been deposited in it.

Considerable quantities of ore have been raised from the Thorngill veins. The position of these veins is favourable to the deposition of lead ore on the principle of a circulation of fluids. Skirting as they do the sides of the mountain in a direction nearly at right angles to its greatest rate of inclination, they must have intercepted the course of the fluids as they flowed to the surface. On account of the breaking up of Black Ashgill cross vein, these east and west veins are subjected to an increased percolation and circulation of fluids under the *fourth law.* Under the ridge forming a kind of water-shed between Blaygill Burn and the Tyne river, the Thorngill veins have contained no lead ore. On the west side of this ridge, Thorngill vein contained a rich deposit of lead ore, restricted, however, to the strata above the Great Limestone. In this ground the Sun vein was only poor. Still further west, in the Great Limestone near the surface, these veins, as well as the numerous weak veins which intersect or combine with them, must have suffered much change by the decomposing influence of atmospheric agency.

Slote vein has also contained ore only where its situation is favourable to the percolation and circulation of fluids. Under the summit of Newshield Moss it contains none. Still further east, near to Blaygill cross vein, where it is called Goangill vein, it has been proved to some extent, but the lead ore it contained was too poor to repay the cost of extraction.

I do not possess much information respecting the width and throw of Taylor's Grove vein. The conditions for promoting the percolation of fluids are modified by the *second law;* in other respects they do not appear to be very unfavourable.

Their circulation, however, is parallel to the direction of the vein, which, as already observed, appears to be less promotive of the deposition of lead ore, than when the direction of the vein, and that in which the fluids flow over the surface make some considerable angle. The lead ore deposits in Taylor's Grove vein have been very poor, and so far as proved have not repaid the cost of extraction.

Clargill and Aleburn veins are proved to a considerable extent, and found to contain very little lead ore. The conditions do not appear to be unfavourable for promoting a free percolation and circulation of fluids in the district traversed by Clargill veins. I am informed, however, that the strata are much broken with joints, and consequently their contents will have been subjected to the decomposing effects of atmospheric agents, and this remark more especially applies to Aleburn vein. It was for proof of this vein that a level was made by the Lead Company some seventy or eighty years ago. In the level an opening was first made into Aleburn cavern, described in Mr. Sopwith's account of the mining district of Alston Moor.

We have now pointed out the connection between the laws regulating the percolation and circulation of fluids, and the lead ore deposits found in the veins of the Coal Cleugh mining district, and those traversing the mountain situated on the east side of the Nent river. In relation to the *first law*, the modifying condition of position of the strong cross veins is not much varied on account of their direction being nearly parallel to the river. The varied vertical positions into which the strata are placed by their great throws, as well as the combination of these powerful veins with each other, and the denudation of the lead ore-producing strata from the west side of Carrs vein complicate the inquiry. On the whole, as an illustration of the *fifth law*, it is probably all that can be expected.

Throughout the whole extent of these veins, in the depressed strata on the east side of Carrs vein, no ore has been found of any importance in them, no matter whether their direction be east and west, or north and south, except at two or three points where the denudation of the strata on the west side of this vein has been effected so low as to allow of a circulation of fluids under the proper conditions, and especially promoted by the *fourth law*. Again, the peculiar conditions connected with the Middle Cleugh veins, Rampgill and Scaleburn veins and their continuation in the Coal Cleugh district—the great number of east and west veins which terminate at Carrs vein—the throws of the cross veins and their contiguity to the watershed of the mountain—render the connection between the *first law* regulating the percolation of fluids and the deposition of lead ore less obvious than may be desired. It will, however, be observed upon the general map, that none of the veins on the north side of Scaleburn vein contain lead ore under the summit of the mountain.

CHAPTER VIII.

OF THE CONNEXION BETWEEN THE LAWS OF HYDROUS AGENCY, AND THE DEPOSITION OF LEAD ORE IN THE VEINS TRAVERSING THE MOUNTAIN MIDDLE FELL.

WE shall now endeavour to point out the connexion between the laws regulating the percolation and circulation of fluids, and the ore deposits which have been found in the veins traversing the mountain of Middle Fell, which separates the Tyne from the Nent river. The east and west veins are numerous, and in most cases can be identified on each side of the mountain. In this district only two important cross veins exist; Garrigill Burn old Groves vein on the west side and Black Ashgill cross vein on the east side of the mountain. Compared with the great cross veins, which traverse the country on the east side of the Nent river, these two veins may be considered as possessing only a moderate width and throw; and with the exception of one or two places, the strata have not been placed by them in a position unfavourable to a circulation of fluids.

It may be observed upon the general map, that at the head of Black Ashgill and Caple Cleugh Burns, the Firestone is the highest stratum; and at this point, the lines denoting its outcropping on each side of the mountain curve in so much, that only a small distance intervenes. Now, it is evident that the

water which flows over the broad slopes of the higher east and west range must fall into Caple Cleugh and Black Ashgill Burns to be carried off in a different direction; and also, that the supply of fluids maintaining the increased percolation (in accordance with the *first law*) at the bottom of the mountain must be abruptly cut off. The consequence is, that the supply of fluids, flowing over the surface, and circulating in the interior of Middle Fell is dependent upon, or derived entirely from, the precipitation upon its surface; thus forming conditions less complicated, and of a more simple character than is generally found in other mining districts.

We left off investigating the connexion between the laws effecting the percolation and circulation of fluids and the lead ore deposits in veins, at the point where the Middle Cleugh veins cease to contain lead ore in the Great Limestone; we shall now resume the investigation at the same point, and commence with a portion of ground which comprehends Caple Cleugh north and sun veins on the west side of Carrs vein. This portion of ground has already been partially described; these two veins traverse the hollow or gap, which isolates Middle Fell from the east and west range of mountains, the water flowing over the surface in opposite directions towards them. Altogether the conditions are favourable for promoting the percolation of fluids, and also their free circulation in the interior of the earth.

These two Caple Cleugh veins are very weak near their intersections with Cowslitts cross vein, and the north vein is altogether broken into weak leads before reaching Carrs vein. Under such conditions, no lead ore of importance could be deposited in them; although, in accordance with the *fourth law*, they have evidently caused much lead ore to be deposited in flats formed in the Great Limestone on the west side of Carrs vein. On the west side of Cowslitts cross vein, the north vein

contained much lead ore, in all the strata, from the surface to the bottom of the Great Limestone. Near Caple Cleugh Burn, the Sun vein also contained lead ore deposits to the same depth. As these veins approach the water shed of Middle Fell mountain they cease to contain lead ore in the Great Limestone, and thus verify the connexion between the *first law* and the deposition of lead ore.

The ground, lying on the north side of Caple Cleugh north vein, traversed by Cowslitts cross vein, is connected with conditions favourable to the percolation of fluids: and also, by the inclination of the beds, to their circulation in the direction of the vein northward. The Great Limestone bassets to the surface at no great distance from the east and west vein. It is also thrown up by Carrs vein above its average horizontal position, and lies at no great depth below the surface, which is covered with a thick bed of clayey alluvium. The vein also skirts the bottom of a steep hill, and must be subjected to the numerous intersections of weak east and west leads, which are said to have enriched Carrs vein. Taking all these favourable circumstances into consideration, it is not surprising that this rather weak cross vein should contain considerable quantities of lead ore.

The ground traversed by Cowhill vein and lying opposite and parallel to the rich ground in Cowslitts cross vein, just noticed, is however connected with conditions very different for promoting the percolation of fluids, passing as it does through the summit of Cowhill. This vein is unproved in this locality; it is supposed to be very weak, and under these circumstances, it seems probable that, when tried, it will be found to contain no lead ore.

To the north of Cowhill, the surface of the country sinks with no very rapid inclination to the junction of Dowgang Burn with the Nent river. This portion of the Nenthead district,

known as Shaw side, is on the whole favourably situated for promoting the percolation of fluids under the *first* and *second laws.* The conditions for promoting a circulation are likewise equally favourable.

For a short distance on the west side of Carrs vein, Hangingshaw vein contained a very rich deposit of lead ore in the Great Limestone; but the portion situated below the summit of Cowhill contains none in any stratum, thus supporting the doctrine that a free supply of fluids from the surface is essential to its deposition. In accordance with the laws of percolation of fluids, Cowhill and Cowslitts east and west veins contained lead ore deposits in the Great Limestone in ground extending further to the west than that in which the lead ore deposits are found in Hangingshaw vein. As these two east and west veins approach the ground where the supply of fluids passing over them from the summit of Middle Fell is cut off by Collier Burn, they cease to contain deposits of lead ore.

Cowslitts and Cowhill cross veins traverse the portion of ground most favourably situated for promoting the percolation and circulation of fluids; and notwithstanding, that in this locality both are weak veins, considerable quantities of lead ore have been extracted from them.

Peat Stack Hill vein, lying opposite and parallel to the productive portions of Cowhill and Cowslitts east and west veins, contained much lead ore in the Great Limestone; and also, like them, it contained almost none under the ridge situated on the east side of Collier Burn.

In the portion of ground bounded by Peat Stack Hill or Briggle Burn vein on the north, and extending southward to Black Ashgill Burn, the conditions for promoting the percolation and circulation of fluids, are subjected to greater variation than those in the ground we have just had under consideration.

Upon inspection of the map, it will be perceived that the veins, in no case, are far removed from the water-shed of the mountain; below which the Great Limestone stratum is placed at a great depth. At Longhole head the Fell top Limestone is the highest stratum. By the *first law*, it is evident that the Great Limestone is lying in a position very unfavourable to the percolation of fluids from the surface, and this has been sufficient to prevent the deposition of lead ore; for although, in some parts of this plot of ground, the veins are much subjected to the influence of the *fourth law*, and in other respects favourably circumstanced for promoting a circulation of fluids, yet, with only one exception, in this stratum they are all alike unproductive.

The exception to which we have called attention occurs in Black Ashgill cross vein, and tends to confirm the laws of percolation and circulation of fluids as essential to effect lead ore deposits in veins. For this very rich lead deposit was found at no great distance from the outcropping of the Great Limestone, in Black Ashgill Burn, and where the Firestone and all the strata above are removed by denudation.

In the third chapter of this book it was attempted to prove, that when veins throw the strata down on the side next the water-shed of the mountain they are placed in a position unfavourable to the circulation of fluids. It would also appear that, except under some very peculiar conditions, connected with intersecting veins, such kinds of throws, when of some considerable extent, are also less favourable to the deposition of lead ore in the vein itself than when the throw is in a contrary direction. Black Ashgill vein throws up the east cheek, and on the Nenthead side of Middle Fell places the deep strata in the thrown-down cheek into an unfavourable position; on the contrary, at Black Ashgill head, the side of the vein, next the outcropping of the strata

is thrown down, and consequently not placed in a position unfavourable to the circulation of fluids. Black Ashgill east cross veins throw up the west cheek; and it is remarkable that in the ground under consideration where the veins are not much subjected to the influences of the *fourth law*, they have not contained much lead ore. It is only under conditions favourable to the percolation of fluids, and where, in their circulation in the Great Limestone, they must settle over the thrown-up cheek of the latter vein, that rich deposits of lead ore have been effected.

The strata on the south side of Caple Cleugh and Longhole head veins, and on the west side of Black Ashgill cross vein, rise rapidly in a direction nearly at right angles to that of the veins. In this ground, the Slate Sills are the uppermost strata. In accordance with the *third law*, all the fluids that percolate the broad summit of Flinty Fell must circulate to these veins. In a portion of Longhole head vein, where it is ramified, large quantities of lead ore were found deposited in these strata; but for 130 fathoms in length directly below the summit of the mountain, the lead ore deposits have not been effected lower than the Firestone stratum. Further east they occur as low as the High Coal Sill. As the broad extent of level surface diminishes, the veins contain less lead ore in the Slate Sills; although moderately-rich deposits have been extracted from them in the Little Limestone and High Coal Sill on the east side of Black Ashgill cross vein. It will be perceived upon the general map, that in this locality, the conditions promoting the percolation of fluids are somewhat similar to those connected with the east part of Rampgill and High Coal Cleugh veins.

The ground, triangular-shaped, enclosed by Longhole head, Black Ashgill and Dowgang veins, occupies a position under the summit of the mountain unfavourable to the direct percolation of fluids from the surface. By the throws of the two former

veins, and in accordance with the *fifth law*, the strata are placed in a position unfavourable to their circulation in any direction; and this unfavourable position is not modified under the *third law*, as the strata are lying in a position very nearly horizontal.

The connexion between these unfavourable conditions and the non-deposition of lead ore is complete. No quantities of the latter of the least importance have been procured from thence.

In the ground traversed by Dowgang veins on the east side of Black Ashgill cross vein, there is a depression of the summit of the mountain, Nunnery rising to some considerable elevation on the north side and Longhole head on the south. Black Ashgill cross vein is ramified, and there are also numerous leads and strings running in various directions. These conditions necessarily modify the *first law* regulating the descent of fluids, causing an increased quantity to percolate near the water-shed of the mountain.

Corresponding to these conditions for promoting the percolation of fluids, the Dowgang veins have contained very rich deposits of lead ore in the Slate Sill, Firestone, Little Limestone and Coal Sills, and even as low as the upper part of the Great Limestone, but, except on the east side of Black Ashgill cross vein, the quantity is so small that it scarcely repays the cost of extraction.

On the north side of Dowgang veins, a long tract of surface, unbroken by deep cleughs or burns, stretches from the Nent river to the top of Nunnery. The principal portion of the water that falls upon Nunnery flows to the north, and this is shown upon the map by the direction of the minor streams. A portion however, circulates over the surface in the direction of Pity Mea and Nenthead Field veins. Before reaching the outcropping of the Firestone stratum, this stream is broken into three parts, one

of which, deflected to the south-east, falls into Dowgang Burn, another continues its course in a straightforward direction, and the last falls to the north; forming a lateral ridge in the immediate neighbourhood of Greengill east end vein.

In this ground two portions of Black Ashgill cross veins contained rich deposits of lead ore. In accordance with the *fifth law*, the throw of the principal one is unfavourable to a circulation of fluids. It will be observed on the map, that this law is modified by numerous intersecting quarter point leads, which would promote a circulation under the *fourth law*. Many of these veins or leads are of considerable strength, and where they are partially collected near their intersection, or combination with Dowgang veins, dislocate the strata three or four fathoms.

It is probable, that the quarter point veins do not extend in their north-west direction further than the cross vein, which occasions the greatest dislocation. In the strata depressed by the throw, two west portions of Black Ashgill cross vein are situated; but as yet no lead ore has been produced from them.

Nenthead Fields veins have not been traced further west than Dowgang east cross vein. Between this point and the outcropping of the Great Limestone the sides of the mountain are very steep, and consequently, under the *second law*, unfavourable to the percolation of fluids. These two veins are not strong, and the lead ore deposits they contained were comparatively poor.

Greengill east end vein traverses the lateral ridge, which extends from the outcropping of the Firestone to the Nent river. Under the *first law*, the conditions are certainly not favourable to the deposition of lead ore. This vein was proved in the Great Limestone upwards of a century ago, and little is now known respecting its contents, except that no lead ore was raised, and that the extensive works made in it incurred a very considerable loss of capital.

On the east side of Black Ashgill cross vein, Greengill east end vein traverses a district favourable to the percolation and circulation of fluids, under the *first* and *fourth laws*. It contained rich deposits of lead ore in the Low Slate Sill, and Ironstone; but in the Firestone below, lead ore was only found in patches; I believe that little or none has been produced from strata below these. A short length of this vein, on the very summit of the hill, is much subjected to the influence of the *fourth law*. The intersecting veins and leads are favourably situated as channels to convey fluids northwards down the sides of the peaked elevation of Nunnery. Here, at the very summit of Middle Fell, a rich deposit of lead ore was lodged in the Slate Sills. Before it was extracted, it had suffered considerably from decomposition. Large quantities of sulphide of lead were found in thick clay beds, rounded and the outsides of the detached lumps converted into a carbonate of lead; in the vein itself beautifully crystallized specimens of the carbonate were obtained. Impure earthy carbonates of lead were also found, the lead and iron apparently cementing the particles of decomposed sandstone into a solid mass.

The lead ore deposits in this ground are not found lower than the Slate Sills; even in the Firestone, which is placed at no great depth from the surface, the little lead ore it contained would not repay the cost of extraction. Altogether this case of a lead ore deposit upon the summit of the mountain, which in a simple empirical law would have constituted an exception not easily explained, furnishes a striking exemplification of the connexion between the laws of percolation and circulation of fluids and the deposition of lead ore.

In connexion with the same conditions, promoting the descent of fluids, but on the north side of Greengill east end vein, and from about the point where the Firestone bassets to the

surface northward to Grassfield vein, the Greengill cross veins, which are a continuation of Black Ashgill vein, contained very rich deposits of lead ore in the Great Limestone. Where these veins are most subjected to the percolation of fluids under the *fourth law*, the richest deposits of lead ore were found.

It will be observed upon the map, that from Grassfield vein the line denoting the outcropping of the Great Limestone bends to the west. For some distance, its direction will not vary much from one at right angles to the greatest inclination of the strata. In this locality, a broad extent of surface is formed of a thick bed of clayey alluvium, and the water, precipitated on the north side of Nunnery, must flow over that portion of the Grassfield veins situated between the outcropping of the Firestone and the Nent river.

It is unnecessary to point out how peculiarly favourable these conditions are for promoting the percolation of fluids under the *first law*. This portion of the district is also much traversed by veins, as well as by weak leads, running in various directions, constituting conditions under the *fourth law* as favourable to the percolation of fluids as those relating to the *first law*. On the line of Grassfield veins, the Great Limestone is for a considerable distance lying at no great depth below the surface. This and the somewhat rapid inclination of the beds on the north side of the vein are favourable to a free circulation.

Grassfield vein, from the outcropping of the Great Limestone to within some twenty fathoms of Grassfield west cross vein, has contained very rich deposits of lead ore, even as low as the Four fathoms Limestone. Between the two east cross veins the strata are elevated by their throws above their general position; and in accordance with the *fifth law* both the east and west veins contained much lead ore.

On the north side of Grassfield veins, and the next in the

order of succession, are the two Gallygill Syke veins. The conditions, however, for promoting the percolation of fluids are very different. In the case of the two latter veins it will be seen upon the map that the outcropping of the Great Limestone approaches that of the Firestone stratum. Hence in the direction of Gallygill Syke veins the hill is much steeper than in the direction of Grassfield veins; conditions which bring the percolation of fluids under the *second law*. The circulation of fluids over the surface more nearly corresponds to the direction of the veins in the former than in the latter case. The correspondence, however, between the conditions affecting the percolation and circulation of fluids and the deposition of lead ore in Gallygill Syke veins is equally striking as in the case of the Grassfield veins, for in the former instance a much less quantity has been deposited, and the length of productive ground far shorter. Though in both instances, westward from about the point where the Firestone bassets to the surface, no lead ore has been deposited in the Great Limestone.

The Gallygill Well and Hudgill Burn veins form a remarkable group, from which—considering the extent of ground and limited vertical depth of the deposits—vast quantities of lead ore have been abstracted. Where the richest deposits were found in the Great Limestone, very thick clay beds form the surface of the country; and near the junction of the outcropping of this stratum of limestone with these clay beds, by driving levels on the line of the veins, detached masses of rock were found, containing much sulphide of lead, which was found changed into a carbonate of lead, where placed in actual contact with the clay: the central parts of the masses, however, remained a sulphide. Had these clay beds not been reposing on the surface, or had the Great Limestone, instead of being covered up by them, formed a line of precipitous cliffs, fissured and broken with

joints, as it assuredly would have been, it is certain that by the percolation of water and atmospheric air nearly the whole of the sulphide of lead would have been converted into a carbonate, and ultimately dissolved and carried off in solution by the circulating fluids. The conserving tendency of these clay beds to prevent the decomposition of the ore, after it has once been deposited, may be illustrated by the fact that a piece of unfossilized wood of about six inches long and four inches broad was found in one of the veins in Hudgill Burn mine. It was surrounded with galena, and situated fifty fathoms below the surface. Mr. Forster states that Mr. Wilson, when relating the circumstance, showed him the specimen.

The percolation of fluids in this district is regulated chiefly by the *first* and *fourth laws*; but peculiarly so under the latter: for the strata are almost entirely broken up with intersecting veins, strings, and leads. Like most of the east and west veins traversing the east side of Middle Fell, this group has contained very little lead ore in the Great Limestone west from the outcropping of the Firestone stratum.

North of the Hudgill Burn veins, the outcropping of the Great Limestone and the water-shed of the mountain approach each other, and consequently the district is less favourably conditioned for the percolation of fluids under the *first law*. For some distance from the line of its basset the Great Limestone is much broken into detached masses, the intervening spaces being filled with clay, and the whole covered by a very thick bed of the same material.

In this district numbers of east and west veins exist, all of which are found to contain no lead ore in the Great Limestone. They are said to be generally straight and weak, and filled chiefly with clay and carbonate of lime. By the laws of percolation and circulation of fluids, it is evident, that if they ever contained

lead ore, it must have been near the present outcropping of the Great Limestone: we may however safely conclude, that the greatest portion if not the whole was abstracted long ago by atmospheric agency, and its place supplied by amorphous masses of carbonate of lime intermixed with clay.

In the ground comprehended inclusively between Bayle Hill and Flough edge veins, the percolation of fluids is chiefly regulated by the *first* and *fourth laws*, and the freeness of the circulation modified by the *third law*.

With the exception of Holey Field and Fair Hill veins, which have lately been worked, the richest portions of their contents were extracted long ago, and no records of these are now extant. Calamine is deposited in considerable quantities in these veins: it has probably resulted from the decomposition of sulphide of zinc, and in some instances has flowed in solution from the veins, and is now found deposited in the joints of the Great Limestone. The metallic contents of this group of veins have in each case undergone, in a greater or less degree, atmospheric decomposition and change. Nattrass vein is peculiarly placed under the *fourth law*, and it seems probable that it is owing to the laws of decomposition that less rich deposits of lead ore were found in it than might otherwise have been expected.

Dowpot Syke veins have only contained small quantities of lead ore, and those chiefly in the upper strata. The Great Limestone is lying below the bed of Nattrass burn, and this circumstance may have prevented a circulation in the vein sufficiently free to effect the deposition of lead ore.

From Flough edge vein the line of outcropping of the Great Limestone is nearly due west, and the course of Nattrass Gill Burn is nearly parallel to that of the Tyne. Here a broad extent of surface is found, which rises gently to the south, forming a

lateral ridge near to Black Syke and Fletcheras veins, while the water precipitated upon Middle Fell must flow into Nattrass Gill Burn, thus isolating a tract of comparatively flat country traversed by the Craig Green veins, and not unfavourably situated for promoting the percolation of fluids under the *first* and *fourth laws.* In accordance with the *fifth law* the strata on the east side of Garrigill Burn Old Groves vein are placed in a position unfavourable for promoting a circulation of fluids.

All the veins in this district have contained rich deposits of lead ore in the Great Limestone; but on the west side of Guttergill cross vein, a great portion of these had evidently been decomposed and carried away by atmospheric agency.

Craig Green middle vein has produced some lead ore on the east side of Nattrass Gill Burn, which was found on the west side of Newberry cross vein, and at a point where the vein is placed under the influence of the *fourth law* by numerous quarter point leads.

The ridge formed between Nattrass Gill Burn and the Tyne, traversed by Black Syke and Fletcheras veins, must modify the *first law* regulating the percolation of fluids. Nattrass Gill Burn cuts deeply into the mountain, and must effect not only the percolation of fluids to deeper randoms than in that portion of ground under the ridge, but also a circulation northwards, or at right angles to the direction of the veins. Black Syke vein throws up the north cheek very considerably, and in accordance with the *fifth law* is unfavourable to a circulation of fluids. Fletcheras vein throws the strata in a contrary direction, and exceeds in amount that of Black Syke vein.

As might be expected from these conditions, Black Syke vein has contained very little lead ore; the little, however, it does contain is found as low as the Great Limestone. In the ridge on the west side of Nattrass Gill Burn this vein is weak, a condition unfavourable to the deposition of lead ore. At the higher part

of Nattrass Gill Burn, Fletcheras vein contained much lead ore in the Slate Sills and Firestone, and some small quantities are found as low as the Great Limestone. Notwithstanding the favourable position in which the strata are placed by the throw of Garrigill Burn cross vein, under the ridge, Fletcheras vein contains very poor deposits of lead ore, especially in the Great Limestone.

The district comprehended between Cross Burn and Garrigill burn, the *first law* regulating the descent of fluids is modified by the *second*. In the upper part of its course Cross Burn cuts very little below the surface, or into the strata. Hundy Bridge and Cowper Dyke heads are the two strongest east and west veins traversing this district; the former near the outcropping of the Great Limestone is ramified, but collected into one vein on the east side of Garrigill Burn cross vein: it has contained much ore in a short length of ground in the Great Limestone. In the upper strata it contains very little vein mineral of any kind. The lead ore deposits in Cowper Dyke heads vein, on the west side of Garrigill Burn vein, have been very poor, as might have been expected from the laws of percolation of fluids. On the east side of this cross vein it contained some little lead ore, but not a sufficient quantity to repay the cost of extraction. In this ground the vein is very weak, not more than a few inches in width. The rest of the Cowper Dyke head veins are too weak to contain much lead ore; the little that has been produced from them was found at their intersection with Garrigill Burn cross vein.

Garrigill Burn cuts deeply into the strata, and, in consequence, the line of outcropping of the Great Limestone is deflected to the east.

In the ground traversed by the Benty Field veins, the conditions are favourable for promoting the percolation of fluids under the *first law;* and where an increased supply has been

effected under the *fourth law*, large quantities of lead ore were found deposited in the veins on both sides of Garrigill Burn.

On the south side of Garrigill Burn, several east and west veins are found connected with conditions favourable to the percolation and circulation of fluids. The Thoughtergill Syke veins contained lead ore, the chief portions of which were abstracted long ago, and their productive character is now in a great measure unknown. About the outcropping of the Firestone stratum most of these veins are weak, and on the east side of this line of rock none of them has as yet produced lead ore.

Browngill vein has contained rich deposits of lead ore in the Coal Sills and Little Limestone; it also contained considerable quantities in the Slate Sills. In the strata above the Great Limestone this powerful vein is ramified, and its throw places broken pieces of Coal Sills and Little Limestone in a series of steps, similar to whatfiis shown upon the following cross section. (Plate XXI.) From the sides of these masses of rock large quantities of lead ore were formerly obtained. On the east side of its intersection with Old Groves vein the aggregate thickness of the ribs of pure sulphide of lead lodged between the detached portions of Little Limestone amounted to from eighteen to twenty-one feet.

In the portion of Browngill vein, comprehended between the outcropping of the Great Limestone and Firestone strata, there can be no doubt but that the conditions are favourable to the percolation and circulation of fluids as low as the Great Limestone. The quantity of lead ore, however, obtained from the vein in this stratum is comparatively small, and sufficient to repay the cost of working only in the neighbourhood of its intersection with Old Groves cross vein, and directly below the very productive ground in the Little Limestone. The throw of the vein places the opposite sides of the Great Limestone past each other. Open spaces have been formed, now filled with quartz and other vein

minerals. In this respect, it differs from the Nenthead powerful cross veins, which, as pointed out, seldom contain much vein mineral when they dislocate the strata very much. Either the lead ore has been abstracted from the vein by some natural cause, or its non-deposition is the result of the interference of some causes at present unknown, but which seem connected with the great amount of dislocation of the vein; for Browngill sun vein, a comparatively weak one, not dislocating the strata more than twelve feet, under precisely similar conditions for promoting the percolation and circulation of fluids, and running in a parallel direction, has contained much lead ore, not only in the Great Limestone, but even as low as the Four-fathoms Limestone. It may, however, be remarked that the lead ore in Browngill vein in the Great Limestone is found precisely where extraordinary deposits might have been expected, had not the effects of ore-producing conditions been counteracted by other unknown causes.

Browngill sun vein, near its intersection with Old Groves cross veins, is straight and weak, and the deposits of lead ore it contained poor.

Southward from Browngill sun vein, no east and west veins of importance traverse Middle Fell, except Wellhope Knot. There is only a short portion of this vein in the Great Limestone, situated very near its outcropping. Under such unfavourable conditions, as might be expected, the vein contained very little lead ore.

We have now shown the connexion between the lead ore deposits found in the veins traversing Middle Fell and the laws regulating the percolation of fluids. The Great Limestone being elevated above the bottom of the valleys is not placed, except in a few instances, in a position unfavourable to their circulation. The tract of amolybdic ground in the Great Limestone, so

clearly shown upon the general map, exemplifies in a remarkable manner the connexion between the *first law* and the deposition of lead ore, and also points out clearly that it is necessary for fluids to be plentifully supplied, as well as to circulate freely in the veins, in order to effect deposits of lead ore. In all cases, such deposits are found only where fluids must freely percolate the surface, and circulate in the veins, and that these conditions only occur where the strata are situated at a moderate depth from the surface, and at some considerable distance from the water-shed of the mountain.

The direction of the dip of the strata in Middle Fell is shown upon the map by means of short arrows. In accordance with the *third law*, it is evident that fluids circulating in the veins would more readily find their way to the surface on the east than on the west side of this mountain, and also the quantity penetrating to great depths must be less in the former than in the latter case. The correspondence between this law regulating the percolation of fluids and the deposition of lead ore is very remarkable, since the greatest portion of amolybdic ground is lying on the east side of the mountain.

Except in limited tracts caused by deep cleughs or burns, the variation in the amount of inclination of the surface above the outcropping of the Great Limestone in Middle Fell is not great: the form of the amolybdic ground is not, therefore, much affected under the *second law;* and perhaps very striking illustrations of this law are not to be found in Alston Moor. We have, however, pointed out a connexion in the case of Hangingshaw vein on the west side of Carrs vein, the two Gallygill Syke veins, and to these might perhaps be added the Dowpot Syke veins.

In accordance with the *first law,* the lateral ridges situated on the sides of the mountain have affected the form of the amolybdic ground in the Great Limestone, the lead ore deposits having

extended further into the interior of the mountain, where the strata above the Great Limestone have suffered the greatest amount of denudation. On the east side of the mountain few of the veins contain much lead ore in the Great Limestone on the west side of the outcropping of the Firestone stratum, and the few exceptions occur only when the veins are peculiarly subjected to the percolation of fluids under the *fourth law.*

The form of this ground has also been modified by the character of the veins. It is an acknowledged empirical law that weak veins are less regularly lead ore producing than stronger ones, and are also worked to a less distance from the outcropping of the strata. The Cowper Dykehead veins furnish the best example of this condition. Of these the sun veins are the weakest, and have contained less lead ore than Hundy Bridge vein, which is the strongest of this group.

Those portions of the veins which are coloured blue have undoubtedly varied considerably in their productive character. Of the portions so coloured, the richest deposits have been effected where from some form of the mountain, the direction of the veins is nearly at right angles to the flow or descent of the water over the surface, and this is more particularly the case where the percolation of fluids is promoted by the *fourth law.* We have already pointed out the Middle Cleugh, Grassfield, and Hudgill Burn veins as exemplifications.

Lastly, its form has been affected by the removal of lead ore by atmospheric agencies; and more particularly so at the north end of the mountain, where the line of amolybdic ground bends to the very outcropping of the stratum. Undoubtedly, many of those portions of the veins denoted upon the map with red and yellow, contained, at some former geological period, much richer deposits of lead ore than when first laid open by mining operations.

CHAPTER IX.

OF THE CONNEXION BETWEEN THE LAWS OF HYDROUS AGENCY AND THE DEPOSITION OF LEAD ORE IN THE OTHER PORTIONS OF THE UPPER STRATA SHOWN UPON THE MAP.

In the district comprehended between Naggshead and the Great Sulphur vein, the Great Limestone, for some considerable extent from its outcropping, is very much broken with joints, and decomposed to such an extent that large "*swallow holes*," caused by the falling in of the roofs of large caverns, are formed at the surface. Many of these have broken through the two hard sandstones above, which in this locality are of very considerable thickness.

The veins which cross Littlegill Burn are weak, and dislocate the strata very little. Of these Littlegill vein is the strongest, and has contained lead ore chiefly in the Little Limestone and strata above. In the ground traversed by this vein on the east side of Littlegill Burn, the conditions for promoting the percolation of fluids are on the whole favourable; but between the outcropping of the Firestone and Great Limestone, their descent into the latter stratum has been prevented by the *second law*. The Great Limestone, for some distance from its outcropping, is in a broken state, and should the vein ever have contained lead ore

deposits, these must have long ago been decomposed and removed by atmospheric agencies. In the ground traversed by this and the other Hole pasture veins, on the west side of Littlegill Burn, the Great Limestone is also very much broken with wide joints. Trials in these veins have been made of considerable extent, but no lead ore of any consequence was found in them.

Windy Brae vein is very much stronger than any of the east and west veins which cross Littlegill Burn. Near the outcropping of the Great Limestone it dislocates the strata not less than twenty-four feet. For a short distance on the west side of the outcropping of the Firestone stratum, and where there are many leads promoting the percolation of fluids under the *fourth law*, rich deposits of lead ore were found in the vein, chiefly in the Great Limestone stratum. Eastward this vein became weaker and ceased to contain lead ore in any stratum.

In the ground between Windy Brae and the Great Sulphur vein, Whetstone Mea appears to be the only vein worthy of notice. I have been unable, however, to obtain information respecting it further than that no lead ore has hitherto been produced from it.

On the west side of the Tyne, three patches of Great Limestone are found capping the summit of the hills. Of these two are very small ones. In the one at Looking Law, very short portions of the broad Mea veins have been moderately productive. The small patch at the head of Duffergill Burn is evidently much decomposed, and broken with joints. It is traversed by the Cornriggs veins; but here they contain no lead or copper ores.

The other patch of Great Limestone is much larger; it lies on the north-east side of the Great Sulphur vein, and extends to Cashburn Force: in it are several veins running in various directions. It is divided by Rodderup Fell west cross vein into

two portions, in each of which the conditions for promoting the percolation of fluids are very different.

In the east portion, the strata rise rapidly in the direction of Dryburn towards the Great Sulphur vein. All the east and west veins that traverse this portion are said to be very weak. Some trials have been made, but no lead ore of any importance has as yet been found in them.

In the other portion the strata dip rapidly in a contrary direction; so much so that, as previously pointed out, the Great Limestone is lying opposite the lower part of the Whin. In this ground the percolation of fluids under the *first law* is (according to the *second and third laws*) much modified by the steepness of the mountain sides and the inclination of the beds. The veins traversing this ground are apparently very strong; but no extensive trials have been made in them, and, so far, have produced very little lead ore.

It will be perceived upon the map, that the ore deposits in Cross Fell veins are found at about the same relative position to the outcropping of the Great Limestone, as those in the veins which traverse Middle Fell. These veins, in their direction westward, become very weak, and hence only give positive instances of the connexion between the laws regulating the percolation and circulation of fluids, and the deposition of lead ore. Had they, however, continued to be strong veins under the summit of Cross Fell, there is every reason to conclude, that they would have contained no lead ore in the Great Limestone.

In the last three chapters we have endeavoured to establish a relation, or sequence, between the percolation and circulation of water below the earth's surface, and the deposition of lead ore in the veins traversing the upper beds. If we have been successful, the original inquiry is modified and presented in the two following aspects:—

1. If the lead ore was originally derived from ascending vapours, and sparsely deposited throughout the whole extent of the veins, then, as the surface of the country became degraded by pluvial and fluvial agencies, the contents of the veins were subjected to decomposition and re-arrangement by the waters circulating below the earth's surface.

2. If the lead ore is derived from the rocks which form the walls of the veins, then the necessary decomposition and re-arrangement in the veins are effected by the circulating waters; the metallic particles being derived from the rocks, or formed from substances set free by their decomposition, and in connexion with unknown laws of chemical combination.

Now if the former theory be correct, it is evident that the metallic ores in veins in the strata below the Great Limestone, must be subjected to decomposition and re-arrangement in the same manner as in the upper beds. We have previously stated as a law of experience, that the veins are less metalliferous in the lower than in the upper beds. This however might arise from the conditions being less favourable to the percolation and circulation of fluids. Before inquiring into the conditions connected with ore deposits in the lower beds, we may observe, that—

1. The Great Limestone throughout its whole thickness is not uniformly metalliferous. It is remarkable, that the most metalliferous parts are certain posts which have undergone the greatest amount of decomposition and change. Rich deposits of lead ore are not often found in the Tumbler beds; these beds, even very near the veins, are seldom much changed by chemical agency. The high flat post may be considered as the most productive part of the limestone, and, as previously pointed out, the amount of decomposition effected in it is truly surprising. Below the high flat post are situated two or three others less

metalliferous; and these are rarely found to be much decomposed. The middle flat post is less metalliferous than the high flat: it is also less decomposable. Similar alternations take place about the low flat post, the bottom of the stratum being the least metalliferous.

2. If the lead ore be derived from the enclosing rock, then either this metal or some lead ore producing principles, whatever they may be, must have existed both in sandstones and limestones.

3. As the veins in the sandstones often contain *very rich* deposits of lead ore, although this kind of rock is less decomposable than the limestones; it is probable, therefore, that they contain a greater amount of lead or of some lead ore producing principles from which this metal is formed by unknown laws of chemical combination.

CHAPTER X.

OF THE CONNEXION BETWEEN THE LAWS OF HYDROUS AGENCY, AND THE ORE DEPOSITS IN THE VEINS TRAVERSING THE "LOWER BEDS."

IN Alston Moor, the position of the series of beds called the "*lower strata*" is more varied than the group forming the "*upper strata.*" In some places, they are considerably elevated above the bottom of the valleys, or even basset at the summit of the mountains; in others, they lie buried at great depths, the whole of the upper portion of the Mountain Limestone and part of the Millstone Grit reposing upon them. In the former case, the conditions for promoting the percolation and circulation of fluids in the veins, vary in a manner similar to those connected with the veins in the upper strata; in the latter, because of their being so far removed from the surface, very little variation can occur. The subject may therefore be viewed under two aspects: the conditions connected with the deposition of lead ore in the veins near the surface, and those connected with its deposition at great depths below.

It is in the former case, that the greatest number of trials for proof of the veins in Alston Moor has been made. A glance at the general map will show that the lower strata, in those portions of Northumberland and Durham represented upon it, do not basset to the surface. We shall therefore commence

with an examination of the results of the trials made in the ground comprehended between the outcropping of the Great Limestone on each side of the Nent river.

The Dowgang veins, near the west side of the Nent river, were worked many years ago in the Quarry hazle, but the productive character of the veins is not known. There are, however, no indications at the surface that they contained rich deposits of lead ore. The conditions connected with them for promoting the percolation and circulation of fluids are very favourable. On the east side of the Nent river, these veins have also been proved in the Quarry hazle; and by means of Nentforce level, as low as the Slaty hazle. In some places they contain very small quantities of ore, but not sufficient to repay the cost of extraction. It is evident that, at a great depth below the Nent river, the conditions are very unfavourable for promoting a circulation of fluids in a longitudinal direction. Similar trials have also been made in the Nenthead field and Guddamgill veins, all of which contained lead ore, but quite insufficient to repay costs.

The rapid inclination of the strata would promote a circulation in the Grassfield and Brownley Hill vein; but on the east side of the river the percolation of fluids is regulated by the *second law*. Considerable trial of this portion of the vein has been made, but no lead ore of importance found in it. On the west side of the river the conditions for promoting the percolation of fluids are very favourable . The Four-fathoms Limestone, which is the surface stratum, reposes under a very thick bed of clay. In this ground the vein contained very rich deposits of lead ore, which, however, did not descend so low as the Nattrass Gill hazle. Below this rich ground, in the Four-fathoms Limestone, a Rise was made from Nentforce level into the Slaty hazle; the vein was found to be strait, and contained small pieces of lead ore.

The conditions for promoting the percolation and circulation of fluids in each of the Nentsberry Haggs and Nentsberry Greens veins are apparently similar. Nentsberry Haggs sun vein is, however, the only one that has contained much lead ore, and that chiefly in the Four-fathoms Limestone and Nattrass Gill hazle; near the Alston and Nenthead road the deposits were found as low as the Three-yards Limestone. It is not easy to point out the conditions connected with this vein, which are different from the north veins, and might promote an increased circulation in order to effect the lead ore deposits. Perhaps it has formed the principal channel in which the fluids circulating in Carrs vein found an egress to the surface.

On the west side of the Nent, Nentsberry Haggs veins have produced small quantities of lead ore, chiefly in the Four-fathoms Limestone, and in connexion with conditions very favourable to the percolation and circulation of fluids. Under similar conditions Gallygill Well vein also produced some lead ore in the same stratum.

Northward from Gallygill Well vein, some lead ore has lately been produced from the west portion of Black Ashgill cross vein in the Four-fathoms Limestone. The conditions for promoting the percolation of fluids under the *first* and *fourth laws* are exceedingly favourable. This lead ore deposit has, however, been comparatively poor.

Still further north, and under similar conditions for promoting the percolation and circulation of fluids, this cross vein contained considerable quantities of lead ore in the strata lying near the surface. In a few places these lead ore deposits descended as low as the Slaty hazle; but in the Scar Limestone the vein is filled with little else than calc spar.

In Middle Fell no other veins have produced lead ore of importance in the lower strata, excepting the Tyne bottom veins,

and these chiefly in flats. The flats occur where the veins are very much ramified, and much subjected to an increased percolation of fluids under the *fourth law.* On the north side the strata dip very rapidly from these veins, a condition very favourable towards promoting a circulation of fluids; and but for this circumstance, these veins in the Tyne bottom Limestone would in all probability have contained little of any other kind of vein mineral besides calc spar. In the Whin they are almost filled with this mineral. Benty Field vein has produced no lead ore in the Tyne bottom Limestone, and it is owing to the conditions for promoting the circulation of fluids being less favourable. Certainly the conditions for promoting their percolation in each case do not appear to be much different.

Taking a general view of these results, and remembering that they are the same veins which have produced such enormous quantities of lead ore in the upper strata, that are so very poor in the lower; and also bearing in mind, that the conditions of mineralization in each case must be very similar, it is difficult to arrive at any other conclusion than that the difference arises from a greater proportion of metallic particles or of ore-producing substance (or substances) entering as a constituent part into the strata composing the *upper beds* than must enter into those composing the "*lower.*" To particularize one case, the Browngill veins on the west side of the outcropping of the Great Limestone are connected with conditions very favourable for promoting the percolation and circulation of fluids. Had these veins traversed the upper series of strata, and the Great Limestone occupied the position of the Scar Limestone, there can be no doubt whatever but that they would have contained very rich deposits of lead ore instead of the few poor ones which, with one or two exceptions, have not repaid the cost of extraction.

In the district comprehended between Ashgill Burn and Crook

Burn, many trials of the veins in the *lower beds* have been made, and the poor deposits found in them occur only where the conditions are very favourable to the percolation and circulation of fluids. The Ashgill Field veins produced lead ore chiefly in flats in the Tyne bottom and Scar Limestones, and an inspection of the enlarged map (Plate XV.) will show, that where these deposits occur, how very much the veins are subjected to the *fourth law.* Ashgill Field vein contained some ore in the Six-fathoms hazle. Below the bed of Ashgill Burn the quantity of lead ore extracted was, however, very small.

Most of the veins in the Tynehead district are connected with conditions for promoting the percolation and circulation of fluids very similar to those connected with the veins traversing the upper strata in Middle Fell: indeed, on the south side of the Great Sulphur vein, the rapid inclination of the strata forms a condition for promoting the circulation of fluids more favourable than occurs anywhere in Middle Fell; and, in many instances, so favourable are the conditions for promoting their percolation under the *fourth law* that it is difficult to resist the conclusion, that had the Great Limestone occupied the position of the Scar Limestone, with the rest of the upper strata occupying their relative position above, most of these veins must have contained very rich deposits of lead ore, and this more especially in that portion of the district traversed by the Clargill head veins.

On the west side of Bel Beaver most of the east and west veins have contained poor deposits of lead ore, and these chiefly near the outcropping of the strata towards the bottom of the hill, and precisely where on the principle of a free percolation and circulation of fluids such deposits might be expected to be found.

Providence or Tees-side vein is said to have been rich in the Tyne bottom Limestone, which is lying near the surface thickly

covered with alluvium. At one place where the vein is subjected to increased percolation under the *fourth law*, lead ore has been deposited as low as the Whin and Jew limestone, which are situated at a considerable depth below the bed of the river Tees. The strata dip rapidly in the direction of the Tees, and this circumstance has perhaps been sufficient to promote a circulation, without which, it is probable, that this vein in these strata would have been filled with calc spar, like the Tyne bottom veins in the same beds.

On the west side of the Tyne, and on the south of Looking Law, the conditions for promoting the percolation of fluids into Calvert vein are favourable, and in some places peculiarly so under the *fourth law*. Not having a good plan of this mine many of these intersections are not represented upon the general map. In this vein the lead ore deposits are found near the surface, and, I am informed, seldom effected so low as the Scar Limestone. Possibly more lead has been produced from Calvert vein in the lower beds, than from any other in Mr. Fydell's portion of Priorsdale Manor.

In the Stow Crag and Lee House Well mines Sir John's vein has contained both lead and copper ores; but these are small compared with the quantities of lead ore produced from the Nenthead cross veins. The total quantity of copper ore produced from Sir John's vein in the Stow Crag mine since 1823 amounts to $895\frac{1}{4}$ tons, and of lead ore since 1811, $1766\frac{11}{20}$ tons. From the same vein in the Lee House Well mine $639\frac{11}{20}$ tons of copper ore have been raised since 1823, and $326\frac{5}{10}$ tons of lead ore.

The conditions for promoting the percolation and circulation of fluids in this vein, where these deposits occur, are similar to those connected with the deposits of lead ore in the veins in the upper strata, though a much less amount of effect has been produced in the former than in the latter case. The lead ore deposits

in Sir John's vein occur in strata situated at a moderate depth from the surface, and where an increased percolation of fluids would be promoted by numerous intersections. Its direction is nearly at right angles to the dip of the strata, which from this vein rise rapidly to the Great Sulphur vein. And its situation on the side of the mountain is very favourable to the percolation of fluids under the *first law*. We may therefore conclude, that a principle of circulation of fluids is as essential to the deposition of copper as of lead ore. Indeed, both were found blended together in a manner very similar to that of the lead and zinc ores in the Nenthead veins. Some copper ore was raised from Sir John's vein on the north side of Crossgill Burn, and many years ago a small quantity at Dryburn.

It is remarkable that the richest deposit of copper was found in the vein when its walls or cheeks were formed of sandstone containing much crystallized iron pyrites. Are cupriferous veins often found in rocks in the composition of which sulphide of iron enters abundantly?

Between Calvert and Rodderup Fell veins the east and west veins have contained scarcely any lead ore. Trials have been made to prove them in localities, where the conditions for promoting a free percolation and circulation of fluids, are as favourable as those connected with veins in the upper beds, which have contained rich deposits of lead ore; thus tending to support the hypothesis, that the poor deposits of lead ore in the veins in the lower beds are due to the paucity of metallic particles, or to some unknown lead ore producing substance not entering so abundantly as a component part of the enclosing rocks.

To the general poverty of the veins in the lower strata Rodderup Fell vein presents a remarkable exception. Large quantities of lead ore have been produced from it since first opened into in 1831.

This vein is a combination of Craig-Green-Middle and How Hill veins, and is wide and well mineralized; it throws up the north cheek about fifteen feet, a throw nearly equal to that of Rampgill vein in the Nenthead district.

In its direction westward from Slaggy Burn, the surface of the country is so thickly covered with clay and other alluvium, that the outcropping of the strata cannot be traced, except close to the banks of the Black Burn. The situation of the vein is considerably to the south of the steep banks of this stream, and under such thick deposits of clay, &c., as must have in a great measure prevented the decomposing action of atmospheric agents upon the lead ore it contained near the surface.

The course of the vein is at a considerable distance from the summit of the hill, and the elevation of the surface is not very rapid. Its situation, according to the *first* and *second laws*, is therefore peculiarly favourable to the percolation of fluids. The direction of the vein makes an angle of about 55° with that of the water-flow over the surface of the country, a circumstance connected with some of the richest veins in the upper beds, and apparently much more favourable to the deposition of lead ore than when the veins traverse the country in a parallel direction.

The strata in this locality have a very rapid inclination, and the dip must be nearly at right angles to the direction of the Great Sulphur vein; consequently, on the line of Rodderup Fell vein, the strata rise in a direction from the east to the west. The circulation longitudinally in the open spaces of the vein in hard strata must therefore have been to the east. It will be seen upon the map, that the strata on the south side of Rodderup Fell vein must be much fractured or broken by intersecting veins and leads. Indeed, the whole of the east and west veins, which traverse Middle Fell and cross the vale of the Nent between Long Cleugh and Gallygill Syke veins inclu-

sively, fall into those portions of Rodderup Fell vein containing the richest deposits of lead ore. Nor can there be any doubt, but that the numerous small leads into which these veins are ramified have been channels in which fluids have been collected and conveyed to Rodderup Fell vein; thus placing this vein peculiarly under the influence of the *fourth law*. It is remarkable, that such fluids after flowing in the leads in a north-west direction would be forced to flow in a direction opposite, or nearly due east. We have already shown, in the case of some of the cross veins in the upper strata, that an abrupt change from a higher to a lower level appeared favourable to the deposition of lead ore; in this case an abrupt change in a horizontal direction appears to be no less so.

Rodderup Fell vein is intersected by two cross veins, both of which throw up the west cheek; and like the east and west veins in the Nenthead district on the west side of Carrs vein, it has contained very rich deposits of lead ore in the strata elevated by the throws of these cross veins.

All the conditions favourable to the percolation and circulation of fluids are found connected with Rodderup Fell vein, and so combined with each other, that they must have performed their functions in a peculiarly effective manner. We are therefore justified in concluding, that the laws regulating the percolation and circulation of fluids in the *upper beds* are also essential to the deposition of lead ore in the *lower*, but that, on account of the strata forming the lower beds containing either less of metallic particles or of some unknown ore-producing substance, or that entering into the composition of the rock in some less soluble form, it is necessary, in order that equally rich deposits of lead be lodged in the veins in the *lower beds*, that *all* the various conditions connected with rich deposits of this metal in the *upper strata* be combined and *intensified in degree*.

Victoria vein has contained a small quantity of lead ore, which as a whole hardly repaid the cost of extraction. It is of less magnitude than Rodderup Fell vein, dislocating the strata only three feet, north cheek up. Veins of like magnitude, and connected with conditions very similar, have contained rich deposits of lead ore in the upper strata; for instance, Middle Cleugh north vein. Victoria vein is less connected with the percolation of fluids under the *fourth law* than Rodderup Fell vein, although all the other conditions for promoting the percolation of fluids are nearly the same. It does not seem improbable, therefore, that the deposition of lead ore in such large quantities in the latter vein is due in a great measure to this law.

A number of east and west veins cross Shield Waters, all of which have been proved to some considerable extent. The quantities of lead produced from them during the last eighty years and upwards are very small. They appear to be well-mineralized veins, containing much quartz. Indeed it is impossible for any person interested in such matters, to travel over this district without being struck with the large quantity of quartz veinstones scattered in all directions upon the surface. These may however be the debris of the Great Sulphur vein left during the glacial period. The conditions for promoting the percolation of fluids in this portion of the district are not very favourable, and had the veins traversed the upper strata instead of the lower there are no reasons for supposing they would have contained rich deposits of lead ore.

Some of the veins on the south-west side of the Great Sulphur vein contain, or are almost entirely filled with, iron pyrites mixed with sulphuretted ores of copper and antimony. No large quantity of copper ore has been produced from any of them. It may also be observed that iron pyrites is deposited most abundantly when the walls of the vein are formed of the

Copper hazles, or sandstones (as previously pointed out), which contain much crystallized iron pyrites disseminated throughout their mass.

Near the source of Cashburn, Doukburn vein contained lead ore chiefly in the Three-yards Limestone and strata below to the bottom of the Scar Limestone. This ore deposit scarcely descended so low as the Copper hazles; and it will be seen, upon inspection of the general map, that it is situated in that portion of the vein connected with conditions most favourable to the percolation and circulation of fluids.

If the principle of percolation and circulation of fluids is admitted to be a law of causation essential to the deposition of lead ore, then from the survey of the results of trials made to prove the veins in the "*lower beds*" where such strata occupy a position near the surface, it is evident that the poor character of the lead deposits in the veins is due to some cause connected with the enclosing rocks; and whatever that cause may be, it is equally connected with limestone and sandstone strata. The formation of limestone and sandstone strata has been effected under very different conditions and with very different materials. Both, however, agree in being oceanic sedimentary deposits, both being non-metalliferous in the lower beds, and in the upper beds both are highly metalliferous: is there not, therefore, some reason for the supposition or hypothesis, that the lead or lead ore producing principle or substance they contain has been held in solution by the waters of the sea, and precipitated at the time when the strata were formed? In this case it is necessary to suppose further, that at the time when the "*upper beds*" were formed the water was more highly charged with this substance and more of it thrown down to enter into their composition. "In Derbyshire, beds of limestone vary in their mineral constitution, some being of a light yellowish dun, or cream colour (hence called Dunstone) and

containing magnesia; in these strata traces of fossil plants are occasionally found. These magnesian limestones are of granular texture, and extremely hard; they are said to be very rich in lead and calamine, and have been extensively worked." * The appearance of the different beds of limestones in Alston Moor is very similar; that their component parts are different may however be suspected, from the fact that when in a state of decomposition they differ in appearance, and some are less liable to be pulverized and borne away by pluvial agency.

Of late years, the probability of lead ores being plentifully deposited in the veins in the lower beds directly below the ground in which the same veins have contained very large quantities of ore in the upper beds, has been a subject of much consideration.

If the deposition of lead ore is dependent upon the laws regulating the descent and circulation of fluids, it is evident, that in proportion to their depth is the probability of the veins traversing them not containing lead ore; and had the lower beds been equally metalliferous as the upper, the circumstance of position alone would be sufficient to prevent its deposition: but when their non-metalliferous character is also taken into consideration, the probability of finding ore in them, when lying at a great depth below the surface, seems to be hopeless; except in some rare cases, where the conditions for promoting the necessary percolation and circulation of fluids exist. Some trials have been made of the Alston Moor veins, under such conditions; we shall now show how far the results agree with this conclusion.

The Coal Cleugh high sun vein has been proved as low as the Four-fathoms Limestone, in which the richest portion of this

* Mantell's 'Medals of Creation,' p. 948. Sir H. De la Beche, however, observes, that among the limestone beds themselves, some are considered as more favourable, as walls to the vein, than others, and certain of them in which much carbonate of magnesia occurs, are disliked, and looked upon as somewhat unfavourable.—'Geological Observer,' p. 782.

vein contains no lead ore of importance. And as Mr. Nevin informed me, the vein was filled with minerals, rarely associated with rich deposits of lead ore. In the Quarry hazle stratum it contained considerable quantities of lead ore. In this case there does not appear to be any improbability in the supposition, that the fluids, which circulated in this stratum, may have derived their lead ore producing substances from the Great Limestone above; but which were abstracted while circulating in the Quarry hazle, or, a circulation sufficient to effect a separation was prevented by the increased depth. Sir H. De la Beche observes of the veins of Derbyshire that "in cases where a fair proportion of galena has been found in fissures through the *toadstones*, it has usually happened that the vein traversing the limestones above or beneath, and sometimes both, contained much ore; it thus appearing as if a superabundance of the ore found its way amid the toadstone, the effects due to the limestone being sufficiently powerful for the purpose."*

This vein on the Alston Moor side of the boundary has not been much worked in the Quarry hazle. Some trials have however been made, and the lead ore deposits in it appear to be poor. It has also been proved in the Four-fathoms Limestone, the appearance of the vein and the results were similar to those in the Coal Cleugh district.

Two patches of lead ore were found deposited in Scaleburn vein in the Quarry hazle, where it is much subjected to the influence of the *fourth law*, by the intersection of quarter point leads forming a condition favourable to a circulation of fluids to the vein. Above these deposits in the Quarry hazle, in the Great Limestone and strata above to the top of the Pattinson, the vein was filled in each case with very rich deposits of lead ore; even

* 'Geological Observer,' p. 782 (note.)

from the vein in the plate beds considerable quantities were extracted. As in the case of Coal Cleugh and Rampgill vein, this vein in the Four-fathoms Limestone, immediately below the rich ground, contained no lead ore.

Contrasting these two or three instances of veins producing lead ore in the Quarry hazle, and none in the Four-fathoms Limestone with the Grassfield veins, in which rich deposits occur not only in the Quarry hazle, but also in the Four-fathoms Limestone, it will appear that the conditions in the latter case differ from those in the former, in little, except that they are more favourable to the percolation and circulation of fluids. The Four-fathoms Limestone bassets to the surface, at no great distance, on the north side of the Grassfield veins, and the inclination of the beds from the veins to this outcropping is very considerable. Where the deposits of lead ore were found in the Grass field veins in the Four-fathoms Limestone—for the ore was not so uniformly deposited in this stratum as in the Great Limestone or even in the Quarry hazle—the veins are very much subjected to the percolation of fluids under the *fourth law*. The lead ore deposits have not been effected so low as the Nattras Gill hazle, which in this district is only separated from the Four-fathoms Limestone by a plate bed six feet thick. We have previously observed that Grassfield vein was proved in the Slaty hazle from Nentforce level, the result being unsuccessful.

Caple Cleugh and Middle Cleugh veins have produced enormous quantities of lead ore, on the west side of Carrs vein, and have only produced it in the Quarry hazle immediately below this rich ground in the upper strata. The quantities, however, raised from them in this stratum are comparatively very trifling, and hitherto, in no instance, has lead ore been found to extend so low as the Four-fathoms Limestone. When the conditions connected with these veins, in this very productive ground in

the upper beds, are contrasted with those connected with the Grassfield veins, where lead deposits occurred in the Four-fathoms Limestone, they differ only in the simple circumstance, that the latter is more favourable for promoting the percolation and circulation of fluids.

In Caple Cleugh mine an extensive trial has been made of Black Ashgill cross vein in the Four-fathoms Limestone, and directly below very rich ore deposits in the Great Limestone. Instead of lead ore, the vein contains little else than calc-spar. The conditions connected with this portion of the vein are not unfavourable to the percolation of fluids. The circulation, however, would probably be towards Ashgill Burn, or contrary to the inclination of the strata; and it may be owing to this circumstance, in connexion with a greater depth from the surface than the Great Limestone, that the vein is simply filled with carbonate of lime: the circulation not being sufficiently free to carry this light substance to the surface. From the cross veins containing less rider and more douk in the plate beds than the east and west veins, the effect of lead ore producing properties of one stratum upon another is in a great measure prevented. When the east and west veins contain lead ore in the Quarry hazle and Four-fathoms Limestone, it is also often found in the plate beds, perhaps poorer, but still in quantities sufficient to repay the cost of extraction, thus showing a connexion between the richer deposits in the Great Limestone and those below. Had the Four-fathoms Limestone been equally metalliferous as the Great Limestone and the sandstones composing the upper beds, it does not seem improbable, but that Black Ashgill cross vein would have contained deposits of lead ore in the ground under consideration.

Some lead ore has been produced from Guddamgill Burn cross vein in the Quarry hazle. It was found chiefly connected with the limestone post which lies on the top of this sandstone, and

beneath a portion of very rich ground in the Great Limestone. The Quarry hazle, where these deposits occur, is lying at no great depth from the surface.

Some lead ore has been raised from Brownley Hill High west cross vein in the Quarry hazle and Four-fathoms Limestone. These ore deposits occur directly below the very rich ground in the Great Limestone; but are very poor when compared with the latter.

Blaygill old vein (Fistas Rake) produced much lead ore in the Quarry hazle and Four-fathoms Limestone, in a short length of ground on the west side of Blaygill cross vein. The outcropping of the Four-fathoms Limestone takes place at no great distance westward from the place where these deposits occur; and the vein is much intersected with quarter point leads. These conditions have evidently promoted the percolation and circulation of fluids, and the latter have perhaps afforded channels for the fluids impregnated with metallic matter derived from the more metalliferous strata above. In this vein, however, the deposition of lead ore has not been effected lower than the Four-fathoms Limestone. About the year 1730 a trial was made to prove it in the Three-yards Limestone and Six-fathoms hazle. A memorandum of this trial still exists, which states, that the "low sills have not answered expectation, as they were expected to be rich, but they may be yet so." Another trial of this vein in these strata has been made more recently, by means of a level driven from Blaygill Burn; the result however was quite unsuccessful. In this case, if a superabundance of lead or lead ore producing matter derived from the upper strata percolated so low as the Four-fathoms Limestone, it was effectually prevented from descending lower by the thick plate beds which lie below the latter stratum.

On the south side of Fistas Rake vein, a portion of Blay-

gill cross vein, about forty fathoms in length, contained a rich deposit of lead ore in the Quarry hazle.

The conditions, for promoting the percolation and circulation of fluids into Browngill sun vein, are somewhat similar to those connected with Fistas Rake vein. By the throw of Browngill vein, the Four-fathoms Limestone is placed in an elevated position, or one in the same plane as the thrown-down cheek of the Great Limestone. Had the throw of this vein been in an opposite direction, no lead ore could have been deposited in Browngill sun vein so low as the Four-fathoms Limestone. Where the lead ore deposits occur in Browngill sun vein in this stratum, the vein is much subjected to an increased percolation of fluids under the *fourth law*. The intersecting leads run chiefly in a quarter point direction. Excepting a sump or two into the Nattrass Gill hazle no trial has been made of the strata below. Admitting the laws of percolation and circulation of fluids as essential to the deposition of lead ore, little hope can be entertained that Browngill sun vein will contain ore deposits in the strata below the thick plate bed under the Nattrass Gill hazle. The conditions are more favourable for promoting the percolation and circulation of fluids to great depths in the district traversed by Fistas Rake vein, in which, as pointed out, no lead ore deposits occur, than in that traversed by Browngill vein. The probability is, that the trial of the latter which is now in progress, will prove a total failure.

Such are the results of mining in the beds below the Great Limestone in Alston Moor. This series of beds occupies the whole of the area of this mining district, the upper strata being left by denudation reposing upon it in patches. The lower beds are traversed by the same veins under precisely similar conditions for promoting the percolation and circulation of fluids, and, under the *first law*, often more favourably situated than any that are found

connected with the upper; and if Rodderup Fell vein is excepted it is perhaps not too much to affirm, that several of the best veins in the upper strata have singly contained more lead ore than the aggregate of the whole produced from the lower strata. And the greater part of this small quantity has been found in the veins near the surface, showing that its deposition, as depending upon the laws of percolation and circulation of fluids, is more easily prevented by increased depth, than it is in the upper strata, and, as previously shown, in order that lead ore may be deposited in the veins, in such strata, it is necessary that all the conditions of hydrous agency be *intensified in degree.*

From this inquiry into the conditions connected with lead ore deposits in veins traversing the lower beds, nothing has arisen to support the theory of sublimation of metallic particles from great depths, and their subsequent cumulation in patches by hydrous agency. The conditions for promoting the percolation and circulation of fluids connected with some portion of the veins traversing the lower beds, are in a few instances even more favourable than those connected with any of the veins in the upper beds. Yet how very different is the result in each case, notwithstanding the similarity of the circumstances and conditions. I am fully aware that phenomena may be related in causation in modes inconceivable to the intellect, no matter how vast may be its stores of knowledge; *for "subtilitas naturæ subtilitatem sensûs et intellectûs multis partibus superat,"* otherwise, one might have doubted even the possibility of any substance entering into the composition of hard rocks of limestone and sandstone, in such small quantities as to elude the searching investigations of the chemist, and yet vary the intensity of their attraction for metallic particles, whether suspended in vapour or fluids: "the accumulated evidence from all parts of the mineral world," however, "proves that the contents of the veins depend on

the peculiar character of the rocks they traverse. Although this is an acknowledged truth amongst geologists and miners, yet the ignorance or neglect of it has led to numerous practical mistakes. It has been supposed that because veins were rich in one place, the continuation of the same veins must be a continuation of the same riches. But if the veins intersect unproductive rocks, the riches come to an end. The public are often deceived by a plausible project which is brought forward on the strength of the ground being near a prosperous mine. Works have been carried on at great expense in unproductive ground without a chance of success, simply because the lode happened to be in the same direction as in a neighbouring rich mine."* The rich mining district of Alston Moor is no exception to this empirical law. Notwithstanding such facts, trials of the veins in unproductive strata are often proposed by persons professing to be miners. When once begun, it is not easy to divine where or when they will end, the extent and cost being limited only by the pecuniary resources of the proprietors of the mines: and thus in the end they prove ruinous to their interests, and, by destroying confidence, extremely prejudicial to mining interests generally.

By the theory of lead or of some lead ore producing substance entering into the composition of rocks in varied proportions, variations in the amount of lead ore contained in veins under the same conditions are easily accounted for. The decomposition of the limestone and sandstone rocks by fluids circulating in them near the surface, may be effected to as great an extent in the lower as in the upper strata: but in the latter case, it may be that a less quantity of some unknown substance is set free to enter into those combinations necessary to form lead ore.

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* 'Encyclopædia Britannica' (eighth edition), vol. xv., p. 221.

CHAPTER XI.

OF THE DEPOSITION OF METALLIC ORES IN VEINS TRAVERSING CLAY SLATE AND GRANITE ROCKS.

WITH the phenomena connected with veins in the granite and clay slate rocks I am practically unacquainted, and consequently not in a position to prove satisfactorily a connexion between hydrous agency, and the deposition of the different kinds of metallic ores, which are found in veins traversing these rocks. In all mining districts, before the subject can be contemplated from this peculiar point of view, it is probable that additional observations must be made, and the whole body of facts colligated and generalized.

To the uniformity of Nature's laws there can be no exceptions. If the deposition of lead ore in the veins of Alston Moor is due to the percolation and circulation of fluids, it is evident that no land elevated above the sea can be exempt from the action of these agents. They must regulate the deposition of the ores of lead, zinc, copper, tin, silver, and perhaps gold, in other localities and in various kinds of rocks. The laws may be modified by conditions, which in some instances produce a greater complication of effects than those found connected with the veins of Alston Moor.

In the district we have had under consideration, the lead ore has been lodged in the veins chiefly since the Glacial epoch. In other districts the laws of hydrous agency may have been in operation during periods long antecedent to the formation of the sedimentary rocks of Alston Moor. In some of the metalliferous districts in the south of England the inquiry may be much complicated by the repeated submergence and elevation of the rocks, and the consequent denudation effected during these changes by oceanic agency.

In this chapter, nothing more will be attempted, than to point out generally the phenomena connected with veins in other mining districts, which appear to be similar to those described in the preceding chapters of this book.

We have shown that a connexion exists between the decomposable character of the limestone rocks, and the richness of the lead deposits in the veins, where such kind of rocks forms their walls. The same phenomenon appears to be connected with the veins of Cornwall and Devon. Sir H. De la Beche observes: "By carefully comparing the metalliferous localities with each other, where granite and the porphyry, or elvan occur together, we soon see reason to believe that there is much in the structure of these rocks which may have influenced the results observed. In Cornwall and Devon *the miner prefers a* PLUMB *granite or elvan;* in other words, granites or elvans which are in a greater or less state of *decomposition,* and are consequently porous. The china-clay districts of St. Austell are the most marked examples of decomposed granite, and the plumb elvans occur in so many places, and are so spread, that they cannot be said to be confined to any particular district. In some cases the elvans are sufficiently soft to be worked for crucible clay, and in others the felspathic matter has been so removed as to give the elvan the appearance of a coarse sandy rock.

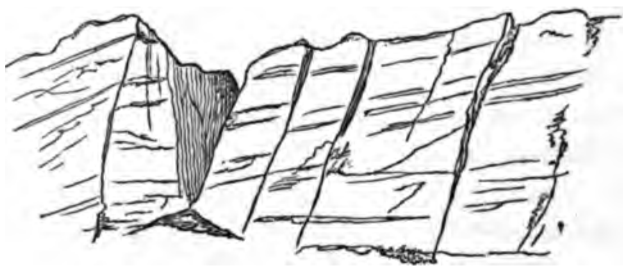
"These decomposable granites and elvans seem to contain, or rather to have been once partly formed of, potash felspars. The extent to which some granites are decomposed in the depths has often been observed, and the fact that hard granite is often intermingled with the soft is also well known. Indeed, decomposed granite seems to have been found at all depths in the mines of Cornwall."* Sir H. De la Beche endeavours to account for the decomposition by the action of the water under pressure and a high degree of temperature. It should be remembered, however, that similar effects have been produced upon the rocks of Alston Moor by water, perhaps under considerable pressure, but certainly not in a high degree of temperature.

The same author states, in another work, that at Penstruthal copper mine the lode had been tried unsuccessfully at various times in parts where the granite was hard; but trial being made where that rock was soft, it became one of the most profitable mines in Cornwall.† And in another part of the same work it is observed that the granite at St. Michael's Mount, Cornwall, is traversed by joints which are well exposed by the insular position of the Mount, and from the united action of the sea and atmosphere, give the granite the false appearance of being regularly divided into vertical beds, ranging about E 10° N and W 10° S. *A change in the structure of the granite is clearly perceptible towards the joints*, and in them are found quartz, mica, topaz, apatite (phosphate of lime), peroxide of tin, wolfram (tungstate of iron), tin pyrites (sulphide of tin and copper), schorl, and occasionally other minerals. What resemblance the joints in the granite may bear to those in the Mountain

* 'Geological Report of Cornwall and Devon,' p. 386.
† 'Geological Observer,' p. 781; ibid., p. 786.

Limestone I am unable to determine. Certainly, no metallic matter was ever found deposited in the joints, traversing the rocks of Alston Moor. Such substances are only found in veins or what originally were fissures, formed by the unequal elevation of the strata. We have already shown that the formation of joints is due to a different cause.

"The long-celebrated Carclase tin mine, near St. Austell, Cornwall, also shows joints filled with mineral matter, including peroxide of tin. Many of these have been worked profitably, *the granite in which they occur being soft from decomposition.* The granite being also white, these joint veins, composed of black schorl and peroxide of tin, mingled with quartz, have a marked appearance, as represented in the annexed sketch.



A large portion of these lines will be found *dipping beneath the adjoining slates,* as is usual with joint lines bounding the masses of Devonian and Cornish granite, and they are crossed by other joint lines, also in the usual manner. A large proportion of the granite country on the north of St. Austell, particularly in the vicinity of Hensborough, exhibits similar strings in which schorl and peroxide of tin are intermixed, and so agree with lines,

representing joints, that they appear little else also than the filling of spaces among such divisional planes by mineral substances finally much harder than the granite amid which they were deposited, *the latter having become to a considerable extent decomposed.* And it is added in a foot-note: "The works upon these small joint veins, and upon the fissure veins also traversing the country, the channels it may have been through which part, at least, of the contents of the former have been derived, are very extensive in that part of Cornwall, the tin ore having been of *excellent quality,* and the granite of the district being easily worked, *from its state of decomposition.*"* So far as I understand this last sentence, Sir Henry has supposed the contents of the joints in the granite to have been derived from the fissure veins. With all deference to such an authority, I cannot help concluding that it was derived from the granite at the time of its decomposition, the conditions being favourable in the locality for calling into action some unknown chemical laws of combination of the substances set free, and of a kind necessary to produce tin ore. The correspondence between the more decomposable parts of the Great Limestone in Alston Moor and the decomposable granite in this instance, in being associated in the former case with pure and rich deposits of lead ore, and in the latter with tin ore of excellent quality, is certainly very striking.

Under present conditions it is evidently impossible for lead ore to be deposited in the joints traversing the rocks of Alston Moor. Indeed, wherever the strata are much broken with joints the sulphide of lead in the veins is always more or less converted into a carbonate, or otherwise decomposed. The

* 'Geological Observer,' p. 787.

question arises whether, at the time of the deposition of the tin ore, the conditions for promoting the descent of fluids into the granite joints were not different from what they are at present. The joints in the granite may have been in existence before the formation of clay slate,—a supposition deriving some support from the fact of the joints dipping beneath these sedimentary rocks. If the joints, now found to contain tin ore, were formerly covered up with clay slate (since removed by denudation), I see no reason why they may not have formed open spaces, into which fluids percolated through the clay slate, to circulate under conditions similar to those found connected with the productive portions of the veins of Alston Moor. If, in the course of future geological changes, the district of Alston Moor should be submerged, and other rocks formed upon it; and if these newly formed rocks were elevated and denuded in such a manner as to promote the percolation and circulation of fluids into the joints now in existence, it is probable that the sides of the joints would undergo decomposition and change; and also that metallic ores would be deposited in their open spaces, as has been effected in the joints of the granite of St. Michael's Mount.

There is another circumstance connected with metalliferous deposits in various parts of the world, which is not at all connected with the lead ore deposits of Alston Moor; I mean the association of dissimilar rocks, one or more of them being of igneous origin. "In Scandinavia the crystalline schists are very rich in metallic ores and other minerals, especially near the intrusive igneous masses, as silver at Kongsberg, cobalt at Modum, copper at Fahlun, Tunaberg, Roras, and Alten; iron chiefly magnetic at Arendale, Utoe, Dannemora and Sala; and in these mines, and also in Finland,

are contained many rare and beautiful minerals."* Humboldt evidently attaches considerable importance to the presence of dissimilar rocks, for he associates the absence of metals from the eastern portion of the American continent with the non-existence of pre-emitting openings, trachytic masses, and perhaps no basalt containing olivine.†

It may be observed that gold is found chiefly in the older Palæozoic rocks, sometimes diffused through the body of such rocks as well as in the intrusive masses of igneous origin. More frequently gold is found in quartzose veinstones that traverse slates more or less metamorphosed. Generally the richest localities for this metal are near the junction of such slates with the igneous rock. Sir R. Murchison supposes that the gold which occurs in quartz veins in the solid slate rocks resulted from an interior agency, in which heat and electricity were combined with water or vapour. He also supposes that the prevalent matrix of quartz, whether ejected from beneath, or poured in from above, was in a soft and gelatinous state when it filled the cavities, resembling the silicious "sinter" which now rises in a fluid spout from Hecla, and falling coagulates into a modern quartz rock around the volcanic orifice. He seems to think, however, that other causes may have modified the effects of heat and electricity. The paragraphs in which this admission is made seem to me so important that I shall transcribe them entire.

"In viewing the widely attested fact of the dispersion of auriferous debris derived from the surface of certain rocks during some of their last great denudations, we are naturally led to favour the suggestion of Humboldt, that the formation of gold had some closer relation to or *dependence upon the atmosphere than*

* Johnstone's 'Physical Atlas.' † 'Aspects of Nature,' p. 360.

that of the baser metals, lead, copper, and iron. An eminent metallurgist, Dr. Percy, who has detected minute quantities of *gold in almost all lead ores*, is, indeed, disposed to believe, that it may have been thrown down by deposition from an *aqueous medium.*

"Whatever may be the correct hypothesis as to the original mode of formation, the fact is undeniable, that wherever the veinstones in the solid rock have not been ground down by former, powerful denudation, but remain as partial testimonials of the origin of gold, the *portions which have as yet proved to be the richest are those which are at or near the surface.* Experience too, dearly bought in numberless instances, has taught the miner, throughout long ages, that in his efforts to follow the veinstones downwards by deep shafts into the body of the rock, he has either found the gold diminish in volume, or so difficult to obtain that the cost of extraction has usually been greater than the value of the metal."*

We have, I trust, demonstrated the dependence of lead and copper ore deposits upon atmospheric agents. It appears, from the observations of these eminent men, that the formation of gold is equally if not more dependent upon this agency, and that the richest veinstones containing gold, as in those containing lead, copper, zinc, &c. (where no decomposition of these has taken place) are found near the surface.

It would appear, however, that the presence of dissimilar rocks may be a condition favourable to the deposition of the precious metals without being absolutely necessary; for the celebrated silver mines of Potosi are situated in an insulated mountain which rises to an immense height, in the form of a sugar loaf, and about six miles in diameter. The mountain is composed of *a yellowish, firm, argillaceous clay*, and is traversed in

* 'Siluria,' pp. 447, 448.

all directions by numerous veins which are filled with ferruginous quartz forming the matrix of the silver ores. These consist of native silver and vitreous silver ore, the latter having yielded on the first discovery of the mine about half its weight of pure silver. *The veins are extremely rich near the surface, but become poorer as they descend,* and in *the deepest part are scarcely one-eighth part so rich as at the top. All the richer veins have been wrought out and exhausted.** From such facts, it is evident that the formation of the ores of silver, as well as these of the baser metals, is dependent upon atmospheric agency, and that the presence of dissimilar rocks is not absolutely necessary.

That the presence of dissimilar rocks may have formed the essential condition to the deposition or formation of metallic ores in some localities must, however, be admitted. At the time of the formation of the elvans, &c., the rocks would be fractured in various directions, and these fractures would be favourable to the percolation of fluids. Besides, the temperature of the rocks, which form the sides or mould, would be much lower than the intruding molten mass; consequently, the cooling down of the latter would leave open spaces into which fluids would percolate to circulate in the intersecting veins. As soon as fluids penetrated these openings, the decomposition of both kinds of rock would be effected, and various metallic ores thrown down from the solution. In some instances, the metallic particles or the ore-producing substance might be entirely derived from the intrusive or igneous rock, and this hypothesis derives some support from an instance, adduced by Sir H. De la Beche as an illustration of the accumulation of either tin or copper ores, when a fissure traversing schistose and porphyritic dykes (elvans) passes through the latter. "The following is a cross

* 'London Quarterly Review,' Oct. 1857.

section of the lode at Wheal Alfred, Gwinear. The elvan dyke, *a b*, is about 300 ft. in width, having a direction about N. E. and S. W., and dipping at about an angle of 45° northerly. The lode *c d* dipping at an angle of 72° to the north, traverses the elvan, *a b*, obliquely in its descent at *e f*. While the fissure traversed the upper and adjoining slate, on the north, no great amount of ore was obtained, but upon entering the elvan it became more rich,

and while passing through that rock the ore was found to be so abundant as to afford a considerable profit (140,000*l.*). After quitting the elvan at *f* in its descent, and entering the slate beneath, on the south, the lode became poor, and eventually the mine was abandoned from the scarcity of ore, the amount of it in the depths not repaying the costs of raising."* In this instance, but for the condition connected with the formation of the elvan the lode would probably have contained no metallic substance of the least value.†

It appears, that in mining districts in metalliferous rocks different in character from the Mountain Limestone, no matter in what part of the world they may be situated, when two veins combine or intersect at acute angles, very rich deposits of metallic substances not unfrequently occur. We have endeavoured to account for this phenomenon on the principle of an increased quantity of metallic particles or some ore-producing substances

* 'Geological Observer,' p. 777.

† This mine has been again worked with an expenditure of 171,330*l.*, "*without any one connected with the undertaking having received one farthing benefit.*"—See Report of meeting, at which it was resolved to abandon the mine, in the 'Mining Journal,' August 24th, 1861.

being chemically combined and thrown down at the point where two metalliferous streams (if we may use the term) combine. We have shown, however, that a circulation must be effected, or no metallic ore will be deposited even at the point of such intersections. If due to chemical combinations it seems probable that the disturbance of the particles held in solution, by the meeting of the two streams, may have occasioned a more energetic action of the chemical laws of combination necessary to the formation of metallic substances; for it may be observed, that when the vein is divided into two or more portions, by the isolation of large masses of rock similar to that which may compose the sides of the vein, it not unfrequently happens that rich deposits occur at one or both ends of the isolated mass.

In some mining districts various kinds of metallic ores are found plentifully in veins at a great depth below the sea-level. It is stated in the last edition of the 'Encyclopædia Britannica,' on the authority of R. W. Fox, Esq., that Tresavean mine has gradually attained to the extraordinary depth of 2112 feet below the surface, or about 1700 feet below the level of the sea.* The Consolidated Mines and several others in Cornwall have also attained a very great depth below the sea level. Professor Phillips observes that there appears to be no limit either to height above or depth below the sea which defines the productiveness of veins, though in some countries the higher and in others the lower situations are most favourable.† Instances of metallic substances being found at great depths below the sea level militate against the law of causation advocated in the preceding chapters. Certainly a free circulation cannot be effected under conditions of this kind. Sir C. Lyell supposes a twofold circulation of terrestrial waters,—one caused

* Vol. xv., p. 223.

† 'Manual of Geology,' p. 541.

by solar heat, and the other by heat generated in the interior of the earth.* It is to the former that the metallic deposits in the veins of Alston Moor are connected in causation. If the circulation from the interior of our planet could really be proved to exist, it might be inquired whether or not it may have affected the deposition of metallic substances in other districts and in rocks of more uniform hardness.

As before observed, the hypothesis of the water's ascending from the interior of our planet appears unphilosophical, and except in the case of volcanic agency has not been satisfactorily proved.

The fact of the ores of various metals being found below the sea level, is best explained by the hypothesis of the land at some former period being raised to a position above the sea sufficiently high to allow of a free circulation to the required depths. In this case, the depths of the metallic deposits become a measure of the height to which the land was elevated above the sea. The period when such deposits were effected in the veins of Cornwall, in relation to the formation of the different groups of sedimentary rocks, may be determinable from facts of a different character. Into this subject it is not my intention to enter, for had I the ability certainly I have not the opportunity of prosecuting the inquiry to a satisfactory result. I will only observe, that on the southern coasts of England, the fact of a change of the relative level of land and water is acknowledged by those who have investigated the subject, to have taken place during very recent geological epochs. It also seems probable, that since the deposition of metallic substances in the veins of Cornwall, the land must have been submerged to a greater extent than at the present time.

* 'Principles of Geology,' p. 238 (ninth edition).

CHAPTER XII.

CONCLUDING REMARKS.

FROM the inquiry respecting the lead-ore deposits in the veins of Alston Moor, now brought to a close, it would appear that either lead in connexion with some basifying principle must enter, in varying proportions, as a component part of the rocks of this district, or some still more elementary substances from which it is formed by laws of chemical combination as yet unknown.

I am not aware that the limestones and sandstones of Alston Moor have ever been subjected to careful chemical investigation. If from their analyses it is proved that lead is diffused throughout their whole mass, then the inquiry would be much simplified, and chemists would be able to demonstrate the changes which must be effected in order that sulphide of lead may be deposited in the veins by the agency of circulating waters.

Should the most searching investigations fail to discover lead in the rocks, in this case I should feel inclined to adopt the other hypothesis, that this metal is formed from still more elementary substances as yet unknown in a separate state, but set free by the decomposition of the rocks, and held in solution by the circulating waters. As yet chemists have not been able to analyze pure metallic substances into simpler elements, but we

are assured in the history of chemistry and by the opinion of some of the best thinkers and experimentalists, that their supposed elementary character is "a mere passing idea."* Should this hypothesis be correct, then the comparative non-productive character of the veins in the lower beds would be due to the small quantity of these substances entering into the composition of both limestone and sandstone rocks.

What these unknown substances may be is certainly not my province to inquire; I may observe, however, that after Sir H. Davy had formed the amalgam from ammonia and mercury, he was led to regard the former as a kind of type of the composition of the metals. He also observes, that by supposing them and the inflammable bodies different combinations of hydrogen and another principle as yet unknown in a separate form, all the phenomena may be easily accounted for, and will be found in harmony with the theory of definite proportions.†

According to the very careful analysis of the waters of the English Channel by Schweider, they were found to contain a distinct trace of ammonia. This alkali is also found in many rocks forming the earth's crust. A perceptible quantity of it combined with acids is found in mineral springs. Water falling from the atmosphere upon decaying vegetation, &c., must take up a portion of it in solution, and in this way it may be carried to great depths below the earth's surface by the percolating waters. Should Davy's conjecture respecting ammonia forming a definite part of what are now considered as simple substances be verified, it would strengthen the analogy which already to some extent exists, between the production of at least some kinds of vegetable matter and crystallized mineral substances.

* Oersted's 'Soul in Nature,' p. 88.
† Works, vol. iv., p. 359.

Should the former hypothesis be the correct one, then it is probable that lead will be found in sea-water, and the highly metalliferous character of the *upper beds* would be due to its precipitation in greater abundance at the time of the deposition of the upper part of the Mountain Limestone.

Recently the presence of silver and copper has been detected in sea-water by Malagute, Field, and Piesse. It is calculated that in the course of six years the copper sheathing of the vessels of England, France, and America acquires from the sea nine tons of silver. Probably the motion of the vessel in the sea-water is a condition accelerating the combination of copper and chlorine; hence a greater quantity of the metal silver must be deposited than if the vessel remained stationary in still water. The conditions of motion and decomposition are similar to what takes place in veins where the metal lead is deposited; for even on the supposition (which I conceive to be improbable) that neither lead nor the elements of lead are contained in the rocks of Alston Moor; so different are their metalliferous character that it is evident, from their decomposition by corroding fluids circulating in them, some substances are set free in varying proportions, which promote chemical changes ending in the deposition of sulphide of lead.

It is very desirable that careful chemical analyses of the different parts or beds of the Great Limestone be made, in order to find out what occasions a greater susceptibility of decomposition in those portions or layers in which flats occur. It seems very probable, that a greater proportion of some substance may be found in the more metalliferous layers than in those which are less so. The limestones forming part of the lower beds should also be subjected to analyses, and the results compared with those of the Great Limestone. The sandstones possess a varied degree of metalliferous properties; the limestones, however,

being chemically formed rocks, I think the results of their analyses could be more depended on.

It is also desirable that the limestone in flats, which is metamorphosed, but which remains *in situ*, should be analyzed, and the result compared with that of the same layers which have not been affected by decomposing and other chemical agencies. Limestone of this kind is much harder than pure limestone; its analysis would show what it has lost, and what substituted. It is upon limestone of this kind, which has evidently been at one time in a softened or semi-plastic state, that the lead ore found in flats is deposited.

On the supposition that these analyses fail to detect lead in the rocks, it can scarcely be expected that they will throw additional light upon the composition of pure metallic substances. Dr. Whewell observes: "As to the possibility of a further analysis of our supposed simple bodies as compose a well characterized class, no such step can be made, except through some great change in chemical theory, which gives us a new view of all the general relations which chemistry has yet discovered. The proper evidence of the reality of any supposed new analysis is, that it is more consistent with the known analogies of chemistry, to suppose the process analytical than synthetical."* In the analysis of metalliferous rocks, should any substance be discovered, which is not so abundantly disseminated in those which are less so, it might ultimately prove a step leading to the great change in chemical theory that Dr. Whewell supposes must take place when the simple bodies are resolved into others of a more elementary character.

In connexion with this subject we may be permitted to observe, that except under some peculiar conditions it seems

* 'His. Inductive Sc.,' vol. iii., p. 158

probable that sulphide of lead is not deposited *very near* the surface, though by the degradation of the latter by pluvial agency, &c., the former is sometimes found in the veins at no great depths ; but in such cases, as might be expected, it is generally found more or less changed into a carbonate. From this it would appear, that when sulphide of lead is deposited in veins, the circulating water contains less oxygen than that which falls from the atmosphere, and a considerably increased quantity of carbonic acid in solution.

I see no reason why ores of lead and zinc may not at the present time be in the course of deposition, wherever the conditions are favourable. It is certain, that not only portions of the enclosing rocks, but also many minerals, are now in the course of being removed from the veins by the waters circulating in them. The deposition of metallic substances may take place very slowly, even under the most favourable circumstances. From facts connected with the extremities of some rich lead ore deposits, one might be led to infer that galena is deposited in small crystals, called by the Alston Moor miners, "buttons of ore." These crystals dot the sides of caverns ; and it is probable that, but for the interference of mining works, all the open space might be ultimately filled by a continued increase in the size of the crystals, and the formation of new ones. In some instances, lead and zinc ores may directly fill up the vacancy formed by the decomposition and removal of other mineral substances by the circulating waters, thus forming that intimate mixture of ore and earthy matter which is termed by the Alston Moor miners "brangled rider."

If the deposition of lead ore is due to a circulation of mineral waters, it is evident, that the veins in the upper part of the mountains would be first subjected to this law, and consequently, it would be in such positions that the first deposits

would be effected. These would gradually be extended to deeper parts of the vein as the land emerged from beneath the sea; their comparative richness depending upon the metalliferous character of the strata, and other conditions connected with the percolation and circulation of fluids. It seems probable, that, in many localities, particularly in the Great Limestone in elevated positions, the earlier lead ore deposits have since been removed by atmospheric agency.

The lead ore deposits in flats in the Tyne bottom Limestone scarcely ever extend beyond the outcropping of the Scar Limestone; the thickness of rocks intervening between these two limestones being sufficient to prevent the deposition of lead ore in the former. In Ashgill Field lead mine, a large quantity of lead ore was found in the flats in the Scar Limestone; but directly below, the flats in the Tyne bottom Limestone contained no lead ore of any value, although, near the veins, the flat posts of this limestone were rendered extremely flinty and hard, and the open spaces contained various kinds of vein minerals, chiefly, however, pure lime and quartz.

In the Tyne bottom mines, there is reason to suppose, that the lead ore has been deposited in the flats at a comparatively recent period, and one long posterior to the glacial epoch; for, it is very probable, that a great thickness of rocks, lying above this limestone has been eroded and carried away by the Tyne river since that time; and until this was effected to some considerable extent, it does not appear that much lead ore could be deposited in the flats.

After a careful perusal of the preceding pages it will be unnecessary to inform those interested in mining speculations in Alston Moor that the productive character of the veins, as denoted upon the map, relates to the discoveries already made. It has not been my object to give opinions, or draw conclusions

from the laws unfolded in this work, respecting the discovery of new lead ore deposits. This, however, has unavoidably been done to some considerable extent. More careful investigations than I could possibly make may ultimately lead to some modification of those conclusions, especially in the beds above the Great Limestone. In this stratum generally very considerable portions of the best veins are proved in the amolybdic grounds. But wherever new lead ore deposits may be found, I feel confident they will be connected with conditions promotive of a free hydrous agency.

It was my intention to add a third book, on the history of mining in Alston Moor, embodying a critical application of the principles laid down in the preceding pages. For this purpose I had collected numerous working plans of mines, and much information bearing on the subject. Prudential considerations have however prevented me from carrying this into effect. Mining works are of themselves a record indelibly impressed upon the rocks with a pen of iron; and it is only by the study of these that we can make the experience of the past our own, and this more especially when connected with principles of causation relating to the distribution of metallic ores in veins.

All that now remains is simply to request of the earnest students of Nature, and more especially those of them upon whom devolves the serious responsibility of searching out objects for trial, and also of planning mining works for the attaining of those objects,—

"Si quid novisti rectius istis
Candidus imperti; si non, his utere mecum."

GLOSSARY OF A FEW LOCAL TERMS.

Douk or Douke.—Probably derived from the Saxon *deagan*, to knead or mix with water. It is a soft substance, often found in veins, especially in the strong cross veins, and chiefly where their walls or sides are formed of shale. It is evidently pounded or decomposed shale, though not unfrequently almost as compact as the rock from which it is derived, but differs from the latter in exhibiting no traces of bedding. Exposed to the atmosphere it rapidly decomposes into a blue kind of clay.

Famp.—Is a siliceous bed, composed of very fine particles. It possesses little cohesion, and when exposed to the action of the atmosphere it crumbles into a sandy kind of clay. Beds of famp often separate the hard posts of sandstone; they also contain more mica than the sandstone rocks among which they are interspersed.

Flats—Are the decomposed parts of limestone strata, and often contain deposits of lead ore and other minerals, all of which are spread out horizontally. The following is the definition of a *Flat* or *Flot*, as given by William Hooson, a Derbyshire miner in 1747:—"It is neither Vein, Pipe, Rake, nor Scrin" (the least or smallest kind of vein), "but a place that hath both Length, Breadth, and Thickness, but all uncertain, till we are very well acquainted with them; some of these Flots carry good ore where never Vein was yet Discovered, tho' such are very rare; the other most commonly lies on the Top of the Lime, and are in some Places very Good; these tye to the Vein and run a great way with it; the Dip of the Flot Discovers the Side that the vein lies on, which proves mostly the Hading Side of the Vein; and 'tis observ'd by the Old Miners, that the Flat always lies on that side of the Vein which Faces the Water: this answers in *Wales*, where the mountains lie Bordering near the Sea for the most Part; and it holds good in all inland Countries that do afford Veins, with respect to the Rivers."

Grey Beds.—A stratum formed of a mixture of shale and sand. They often possess a considerable amount of cohesion, and decompose less rapidly in the open air than famp.

Girdle Beds.—Generally very thin beds of a hard and compact kind of Sandstone, which are separated from each other by thin beds of shale.

Hazle.—Probably a Saxon word, which, when used as a mining term, denotes a sandstone that is mined with much difficulty.

Leads.—Very small fractures in the rock, often of no greater width than a bootlace. Leads are often, though not invariably, connected with veins; and in the limestone strata they are frequently connected with flats. Where the fractures in the rocks are sufficiently wide to contain deposits of lead ore that will repay the cost of mining, and are situated near a vein bearing in a somewhat parallel direction, they are called *strings*.

Opening Drifts.—Are horizontal openings or adits made in veins. They commence either at a Shaft or Rise, and do not communicate directly with the surface.

Plate.—Synonymous with shale. It is of varied degrees of compactness, and when exposed to the atmosphere it splits up into small thin plates. Hence its designation in Alston Moor.

Post.—The limestone strata are divided horizontally by *very thin* beds of shale. These are termed posts. Some of these posts are well known, and have their appropriate names; such as the High, Middle, and Low flat posts of the Great Limestone, the Limestone post of the Quarry Hazle. Sandstone strata are also divided into horizontal layers by thin beds of shale or famp.

Rise.—An opening made in the rocks perpendicularly or nearly so is called a Rise. Rises are generally made in the veins, and hade accordingly. When the workmen are employed in making these vertical openings they are said to be *rising*.

Sill.—Denotes a stratum of any kind of sandstone rock; it is rarely applied to limestones. This word is probably derived from the Saxon Syl, a threshold or any flat substance placed in a horizontal position.

Sun.—Synonymous with South. In Alston Moor veins are generally designated by the names of the localities where they are first discovered. When other veins are found near the same place they are often called Sun-veins,—First Sun vein, Second Sun vein, &c.,—or North Veins,—First North vein, Second North Vein, &c.,—as the case may be. Or if the vein first discovered traverses the country in a north and south direction, then the parallel veins are called East cross veins, or West cross veins.

Sump.—A sump differs in no respect from a shaft, except in being commenced from a level or opening drift. Workmen employed in making Sumps or Shafts are said to be *sinking*.

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The map is divided by fine lines into square-mile divisions. The large Arabic numerals and letters of the Alphabet correspond to those upon the border of the map. The small Arabic numerals refer to the particular places in the corresponding square-mile divisions upon the map.

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